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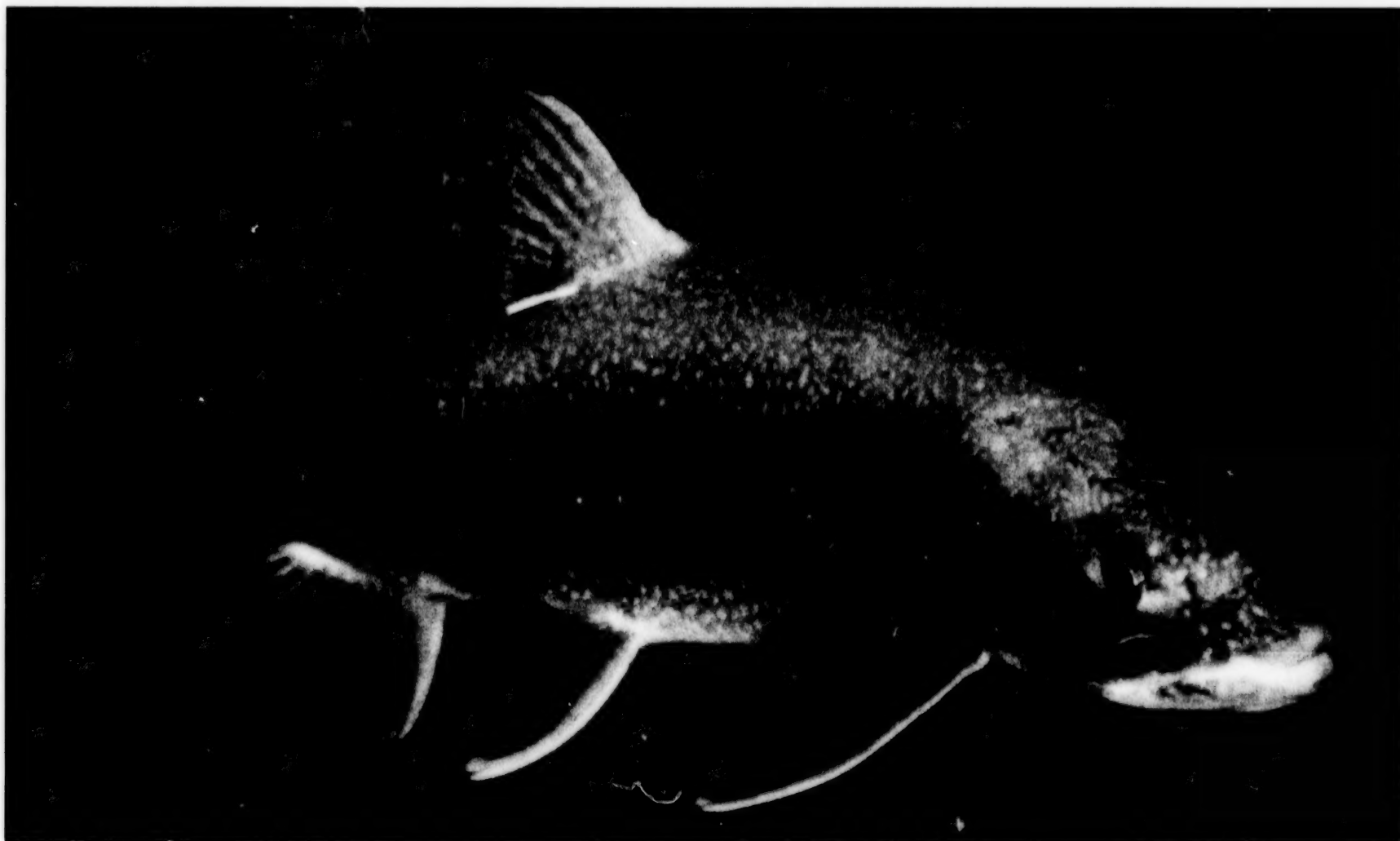
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**Fisheries and Wildlife Research and Development
1989/1990
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UNITED STATES DEPARTMENT OF THE INTERIOR/FISH AND WILDLIFE SERVICE



A male lake trout displays its dark nuptial strip while swimming near the surface of Gull Island Shoal, a spawning ground used by native lake trout. This fish had been previously caught by gillnet and tagged by the Wisconsin Department of Natural Resources. It was photographed at night in the open waters of western Lake Superior near the Apostle Islands area. *Photo by G. Kennedy.*

Fisheries and Wildlife Research and Development 1989/1990

**Activities in Region 8—Research and Development—for
Fiscal Years 1989 and 1990**

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Foreword

The primary objectives of the Fish and Wildlife Service research and development program are to collect, analyze, and synthesize the scientific information needed to conserve and manage the Nation's fish and wildlife resources. The major thrusts of the program reflect the needs and priorities of the country. During fiscal years 1989 and 1990, the Service continued its vigorous pursuit of information on fish and wildlife species and their habitats and on the management of

these resources for social, economic, aesthetic, and scientific benefit. In addition, major research efforts focused on our changing environment and the effects of human-caused changes on fish and wildlife and their habitats.

Much of the major research completed by the Fish and Wildlife Service during 1989 and 1990 is summarized here. The brief accounts presented are intended to represent the Service's diverse research program, as well as to high-

light recent research findings significant to fish and wildlife management throughout the Nation. More detailed research findings are communicated in scientific and popular publications and in workshops, talks, and lectures. Additional information on the Service's work may be obtained from the centers, and cooperative research units mentioned in the summaries, or from the Service's Office of Information Transfer.

The Role of Research in the Fish and Wildlife Service

Consider the possibilities: entering dens of hibernating black bears in the Appalachian Mountains or dens of polar bears in Alaskan ice fields. Extracting DNA from endangered species of birds, plants, mammals, fishes or butterflies. Locating exotic zebra mussels and European ruffe in the Great Lakes or diving with prehistoric-looking sturgeons and paddlefish in the Missouri River. Following the migratory bristle-thighed curlew from Alaska to the South Pacific islands and dancing with whooping cranes and feeding newly hatched California condor chicks with a hand puppet. Identifying foods of such diverse species as squawfish and trout, bobcats and bats, snakes and salmon, or blue jays and bass. Modeling and analyzing research data with sophisticated computers, or maneuvering jet-propelled airboats.

These are but a few of the subjects that Fish and Wildlife researchers turn their attention to: the organisms may be as minute as the invertebrate *Daphnia* or as large as muskoxen. Topics range from the effects of harvest, predation, and habitat fragmentation on waterfowl

populations to the effects of contaminants on fish and wildlife and their habitats. In addition to its regional office in Arlington, Virginia, Region 8 (Research and Development) maintains 13 research centers and 93 field stations throughout the country. Joint research with other nations is more common—and important—as we begin to recognize the finite nature of the world's natural resources and the urgent need for a global approach to conservation.

Research in Region 8 may be as fundamental as theoretical experimentation in search of explanations for natural phenomena. However, most studies rely on already-established principles and are either applied research designed to find solutions to specific problems or developmental research to test techniques, models, or procedures.

The primary responsibility of Research and Development is to support resource managers in the national wildlife refuge and national fish hatchery systems as well as staff in management of migratory birds, listing and recovery of endangered species, and conservation of fish and wildlife habitats. But other Fed-

eral agencies, States, local and foreign governments, private conservation agencies, congressional representatives, and the general public also expect Service researchers in Region 8 to address specific fish and wildlife problems and to provide solutions. The youth of the science of fish and wildlife management, the complexity of natural systems, the inability to carefully control variables in those systems, and the potential effect on natural resource management that research findings might have add a rare degree of depth and excitement to research in the Service. But conducting research on natural systems is not a process that yields reliable information quickly. Thus, Service researchers, like those elsewhere, must not only be well trained, methodical, and tenacious, but they must also be enthusiastic and willing to work under sometimes adverse conditions to advance scientific knowledge. This biennial report is issued in recognition of the accomplishments by researchers and the support staff of Region 8, and their commitment to the conservation of fish and wildlife.

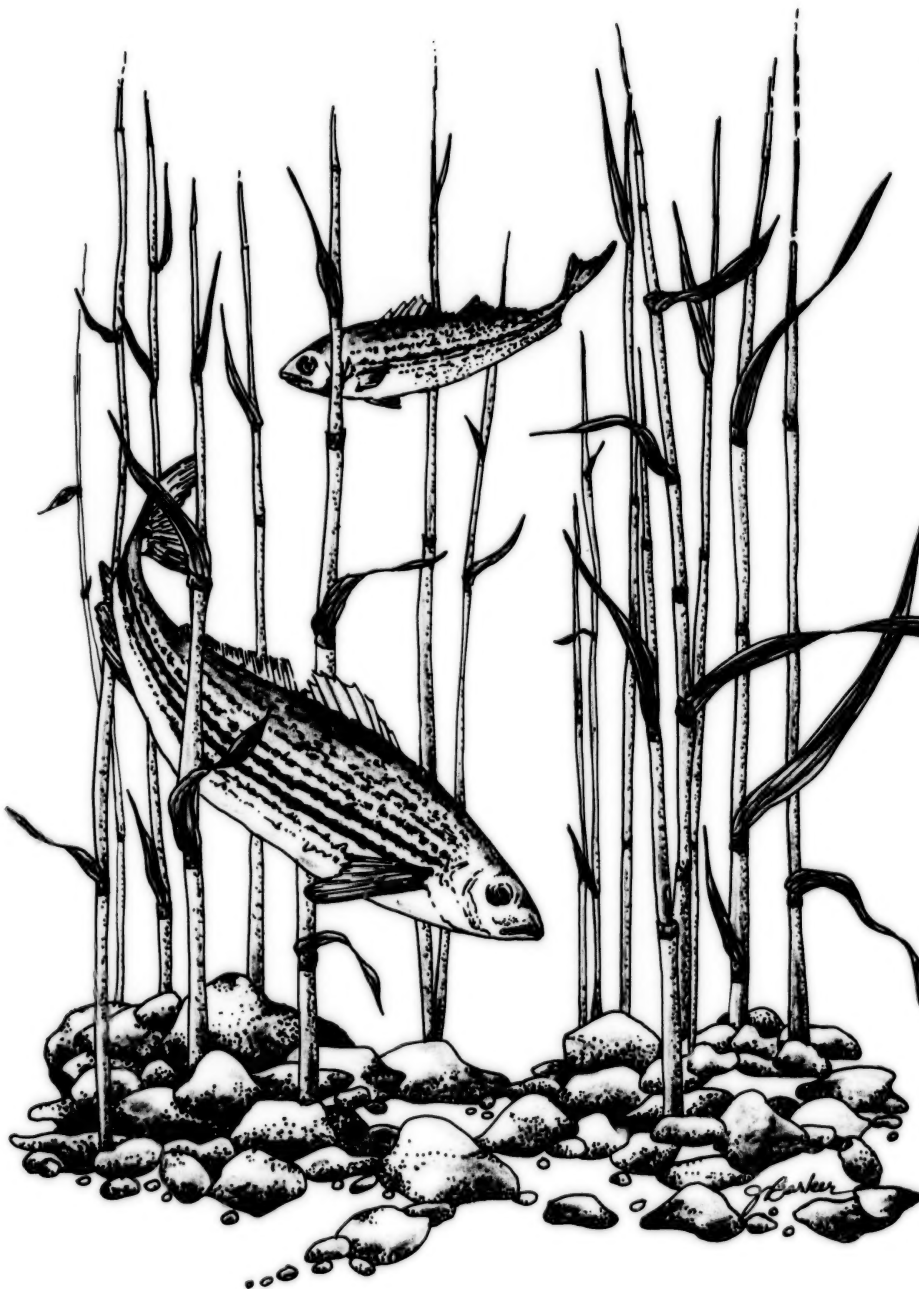
Population Ecology and Management

Mammals

Reduction of Conflicts Between Mammals and Human Needs and Interests

Winter Habitat Use of the Pine Martens

At the National Ecology Research Center, researchers are field testing selected Habitat Suitability Index models used in the Service's habitat evaluation procedures. The model for the pine marten, a small predator related to the weasel family, is being tested because modeled winter habitat requirements do not appear to conform to known marten habitat requirements for subnivean (under snow) access to resting and hunting sites. For these animals, such sites are essential components of winter survival in the central Rocky Mountains. In the winter of 1988-89, biologists began a radio-telemetry study in a subalpine forest of the Sierra Madre in south-central Wyoming. Martens primarily used large logs protruding above snowpack to obtain access to the subnivean space in early winter, and snow-covered branches of small subalpine fir trees as winter progressed and snow depths increased. The subnivean space around the access sites had a high percentage cover of downed wood, high volume of undecayed and moderately decayed logs and stacked logs, but no heavily decayed logs. The model will be modified to reflect these findings and should become a valuable tool for evaluating forest management practices and



maintaining habitat characteristics important to martens.

Deer Populations in National Parks

Increases in white-tailed deer populations in the northeast are a major concern to natural resource managers of national parks and monuments and national wildlife refuges. For example, the density of the deer herd at Gettysburg National Military Park has been estimated at more than 98 deer per square mile during November, and the number of deer killed by automobiles has been significantly higher in the park than in surrounding areas. When the Pennsylvania Cooperative Fish and Wildlife Research Unit investigated the effects of the deer population on vegetative communities in the park, they found that over 34% of the woody stems in the forest understory were browsed by deer. Given the current size of the deer herd, the present stocking of seedlings and saplings may not be adequate to regenerate white oak and other historic species.

On farm fields in the park, browsing deer reduced corn yield by 33% and winter wheat by 30%. The white-tailed deer herd at Gettysburg has exceeded the level that is compatible with regeneration of historic woodlots, production of farm crops, and safe travel on highways. To provide a satisfactory balance between deer and other resources, the herd size must be reduced.

Black Bears and Montana Hunters

The status of black bears in extreme northwestern Montana was studied by the Montana Cooperative Wildlife Research Unit. A density of one black bear per 6.33 miles was estimated for the study area. Captured bears were primarily adult males, indicating a lightly exploited population. However, deaths of marked bears due to hunting was excessive. An annual reproductive rate of 0.7 cubs per female was determined, and at least one female did not produce a successful litter until age 7. The mean home range size for adult males (5+ years), was about 38 square miles

(the size ranged from 14 square miles to 74 square miles). The home range of adult females averaged 18 square miles and varied from almost 7 square miles to nearly 42 square miles. The primary hunting technique hunters used during the spring hunting season was driving open roads searching for bears. Of the bears killed during the spring season, 39% were shot within 109 yards of an open road, and 66% were first observed from an open road.

River Otter Ecology

River otters in Massachusetts appear to be increasing in numbers and expanding their range. Since States are now required to ensure that harvest rates don't hurt river otter survival, Massachusetts asked Massachusetts Cooperative Fish and Wildlife Research Unit biologists to investigate otter habitat use, particularly at their latrine sites. River otters tend to defecate at the same sites, allowing scientists to determine commonly used otter habitat.

Twenty-eight black bears were marked (13 with radio collars) in extreme northwestern Montana during 1986 and 1987 to study population characteristics and effects of hunting. All were caught in foot snares and tranquilized for handling. Jab sticks, as pictured here, were the usual method of delivering the drugs. *Photo by T. Thier.*



Throughout the year, river otters used vegetated wetlands and riverine areas more often than open lakes and ponds. They preferred latrine sites that are on a point of land, at the mouth of a permanent stream, or near large conifers and beaver structures. Management practices that encourage beaver populations and availability of mature conifers along wetland shores enhance river otter habitat.

Coyote Food Consumption in Summer

Biologists at the Mississippi Cooperative Fish and Wildlife Research Unit investigated the summer diet of coyotes on seven study areas in Alabama, Kentucky, Mississippi, and Tennessee in 1985 and 1986. Diets in four areas having a high white-tailed deer density were compared with those in three areas having a low density. Researchers examined coyote feces and stomach

samples for evidence of deer in their diet. On each study area, the samples were separated according to collection dates on each study area: before fawning, fawning, and after fawning. The important foods overall (by frequency of occurrence) were fruit (45.7%), insects (36.5%), rabbits (31.6%), deer (30.8%), and rodents (23.5%). In the areas where deer were densest, deer was the most frequent food item, whereas it was the least frequent major food item in the areas with lower deer densities. Occurrence of deer in coyote diets in the deer high-density areas was 7.1% before fawning, 69.7% for fawning, and 55.4% for after fawning; in the low-density areas, these values were 1.9%, 5.5%, and 7.0%, respectively. Most (76.9%) of the deer eaten were fawns. Rabbits, insects, and fruit were consumed more frequently in low-density areas.

Management of Alaska Mammals

Kodiak Brown Bears and Deer Hunters

In a cooperative study between the Alaska Fish and Wildlife Research Center and the Alaska Department of Fish and Game in the Kodiak Island area, kills of brown bears for "defense of life or property" were examined during 1974-86. The analysis showed that 93 bears were killed in 88 reported incidents, and that hunters were the most frequent (61%) perpetrators. Deer hunters alone were responsible for 53% of such kills. Although the present level of such deaths is probably not detrimental to the Kodiak bear population, the increasing trend is a concern because adult females seem particularly susceptible to this form of killing. Also, an unknown but potentially important number of such deaths are not reported. A continued loss of mature females could depress bear numbers in local areas. Bears



A dramatic increase in deer hunting and harvest on Kodiak Island, Alaska, has increased kills of brown bears for defense of human life and property. Radiotelemetry allows biologists to quantify interactions between deer hunters and brown bears and to collect the valuable bear life history information needed to effectively manage brown bears. *Photo by V. Barnes.*



Most polar bears from the Alaskan Beaufort Sea population build maternity dens in offshore pack ice. Satellite telemetry data suggest that bears that den on land produce more cubs than those that den on offshore pack ice. *Photo by S. Amstrup.*

ranging primarily inland (about 3 miles or more from the coast) appeared to have little contact with deer hunters. Conversely, most radio-collared bears relocated within about 3 miles of the coast were later found near hunting camps and one bear was known to have raided camps. Nearly 50% of the hunters saw at least one bear during their hunts but only 6% encountered a bear in a situation in which the hunter felt threatened.

Pacific Walrus Survey Techniques

Pacific walrus occur in the United States and Soviet Union and are harvested by both nations. Sound management of walrus harvest requires insensitive measures of population status. Walrus are difficult to count and study in their natural habitat. The Alaska Fish and Wildlife Research Center, in multinational research on capture and survey techniques, is also develop-

ing specialized satellite telemetry equipment. In the last 2 years, the center developed methods for immobilizing walrus and for attaching satellite radio transmitters to them. Six satellite collars and six conventional radio transmitters were used on walrus in the Soviet Union in 1989. The transmitters were originally designed to operate for up to 1 year; however, none have functioned longer than 4½ months, and most quit transmitting after 2 to 4 weeks. Although the transmitters were redesigned in 1988, antenna configuration still requires additional research and development.

Sea Otter Ecology

About 98% of the population of sea otters in North America live in Alaskan waters. Development of the coastal zone, increasing conflicts with shellfish resources, and legal and illegal killing of sea otters have justified a major research program on sea otters in Alaska. In 1986, the

The Alaska Fish and Wildlife Research Center has developed methods to immobilize Pacific walrus and to attach satellite radio transmitters to their tusks. Satellite telemetry is useful for determining observer bias in aerial surveys, understanding the overall scope of animal movement, and defining the extent to which the walrus population is shared with the Soviet Union. *Photo by S. Hills.*



Alaska Fish and Wildlife Research Center began a 5-year program to evaluate the magnitude of the conflicts over shellfish (between commercial fisheries and sea otters, which eat shellfish); to develop census, marking, and condition techniques; and to collect information to help formulate a zonal management plan. Sea otter populations in southeastern Alaska are increasing by 20% per year; nearly 5,000 animals lived in nearshore habitats in southeastern Alaska in 1987. Sea otter survey data and catch data for

Dungeness crabs suggested that sea otters reduced the abundance of Dungeness crabs in locations where the two species overlap. At Kodiak Island, for example sea otters are most likely to conflict with commercial fisheries for green sea urchins and Dungeness crabs.

Caribou and Muskoxen Population Ecology

National interest in oil and gas development of the Arctic has spurred research by the Alaska Fish and Wildlife Research Center into

the area's resources, with biological emphasis on the coastal plain of the Arctic National Wildlife Refuge. Each year, this area is used as calving and after-calving habitat by the international Porcupine Caribou Herd and is used year-round by muskoxen and a segment of the Central Arctic Caribou Herd. Calving in the Porcupine herd in 1989 was 3% lower for adult female caribou than the 10-year mean of 82% and calving occurred 1 week later than in the previous year. As in 1988, calving distri-



Petroleum exploration in the Arctic National Wildlife Refuge may adversely affect wildlife numbers and result in a loss of habitat or changes in distribution. Biologists, by using satellite transmitters, are able to track the movements of caribou throughout their seasonal range from wintering areas in Canada to calving areas on the North Slope of Alaska.
Photo by S. Fancy.

bution was influenced by a relatively late snowmelt. The number of caribou deaths was high during the winter of 1988–89, when many stillbirths were found among the dead calves examined by the National Wildlife Health Research Center in Madison, Wisconsin. The part of the muskoxen population that inhabits the coastal plain of the refuge may be stabilizing at about 360–400, whereas other segments of the population continue to increase. In 1989, 15% of 279 caribou classified were calves—a ratio of 39 calves per 100 cows. Productivity and initial calf survival in 1989 were similar to that in 1986, but lower than in 1983–85 and 1988, when calves composed 21–23% of all animals classified, and 66–75 calves per 100 cows were observed.

Management of Mammals on Federal Lands

Elk and Cattle Interactions in Idaho

Elk habitat use, distribution, and nutritional condition, as affected by cattle, were investigated in east-central Idaho by the Montana Cooperative Wildlife Research Unit. Of the two pastures most used by elk, the animals preferred whichever one was ungrazed (rested) by cattle in the early cattle grazing season. Additionally, elk preferred to use a pasture occupied by cattle late in the cattle grazing season rather than an unoccupied pasture that had been grazed earlier in the season. Comparison of diaminopimelic acid levels from elk pellets collected in areas grazed by cattle with levels in areas ungrazed by cattle suggested that dietary quality for elk was unaffected by cattle grazing.

Ear tags are used as a marking device for a mark-and-recapture estimate of squirrel populations conducted by Missouri Cooperative Fish and Wildlife Research Unit. Photo by P. T. Seng.



Food Habits of Mule Deer and Cattle

In another study, biologists from the National Ecology Research Center studied food habits of mule deer and cattle on Sheldon National Wildlife Refuge in Nevada during an evaluation of a deferred rotation grazing system. Mule deer preferred bitterbrush, especially during late summer and early fall. Forb use was greatest in early summer when forbs were growing rapidly, but forb use continued throughout the season on those forbs with persistent green foliage. Grass use was greatest during active leaf growth in early summer and after fall rains. Grasses dominated the cattle diet although bitterbrush dominated late summer use in a year when grasses did not re-green because summer rain came late. The pattern of forb use by cattle was similar to that of mule deer. Even though levels of dietary overlap between mule deer and cattle were high, the findings were consistent with other studies in habitat where bitterbrush is a common forage species in the plant community. Bitterbrush on the refuge lands that are grazed has high annual production and shows no indications of overgrazing.

Bobcat Reintroduction

Bobcats were last seen on Cumberland Island—the largest and most southerly of Georgia's barrier islands—in 1907. In 1972, most of Cumberland Island was acquired by the National Park Service as the Cumberland Island National Seashore, parts of which are a federally designated wilderness area. Part of the National Park Service's mandate is to preserve or restore native plants and animals on National Park Service lands. The Georgia Cooperative Fish and Wildlife Research Unit is evaluating a reintroduction of bobcats to the Cumberland Island National Seashore. In fall 1988, 14 bobcats (3 males and 11 females) trapped on mainland Georgia were equipped with radio collars and released on Cumberland Island. Four dens containing 10 kittens were located. In January 1989, one female was killed and another female swam to the mainland. In fall 1989, 18 more bobcats (12 males and 6 females) were released on the island; one male died shortly after release; the remaining 17 and the 12 previously released bobcats are still alive. At Cumberland Island, bobcats principally prey on marsh rabbits, white-tailed deer, grey squirrels, feral hogs, and various small mammals. All biological information suggests that this reintroduction has been a success.

Moose Biology

Radio-collared Shiras moose were studied in the Yaak drainage of northwestern Montana by Montana Cooperative Wildlife Research Unit personnel. Uncanopied habitats with abundant high-quality forage and good hiding cover were important to moose during all seasons. Forested cover was important during summer heat and deep winter snow, and aquatic sites were important in summer. Principal suggestions for future management include maintaining and enhancing the integrity of key habitat components; pursuing a vigorous road-closure program; designing irregularly shaped forest harvest units that increase the amount of hiding cover immediately available to moose; and creating more low-elevation mosaics of timbered cover and open-browse areas.

Mountain Goat Introduction

An introduced population of mountain goats was studied by researchers at the Montana Cooperative Wildlife Research Unit in the Snake River Range of Idaho. Fourteen years after introduction the population was estimated at 141 goats; modeling suggested their population growth was not substantially affected by density. This population continued to grow rapidly during 2 years of study, but density-dependent changes in the growth rate appeared imminent. A low proportion of kids during the first year of the study, following an extremely severe winter, may have resulted from a density-dependent decrease in survival that year. Reproduction was high during the study, with a yield of 114 kids per 100 3-year-old females. Twinning was common; 29% of mature females biologists observed had twins; 86% had at least one kid. The population's survival rate was estimated at 92–94%. Observed average survival was 88% for

kids, 95% for yearlings, and 93% for subadult and adults.

Migratory Waterfowl

The continuing decline of many waterfowl populations is cause for alarm. Some duck populations are now at record low levels and wetlands and other vital habitats continue to disappear or be altered. Consequently, Federal, State, and private conservation organizations are targeting many of their research efforts toward waterfowl—those creatures of land, sky, and water.

Waterfowl—ducks, geese, and swans—are among the most prominent and economically important groups of migratory birds in North America. They are highly prized as game birds by millions of hunters in Canada, the United States, and Mexico and are treasured by even more people who enjoy observing, photographing, and studying them. Conserving and managing waterfowl populations in the United States is a major responsibility of the U.S. Fish and Wildlife Service.

The North American Waterfowl Management Plan, developed by the United States and Canada, sets a course of action for both countries between now and the year 2000 to assure abundant populations of ducks, geese, and swans. The plan and its associated joint ventures between the two countries are a framework for waterfowl management and research.

Research on waterfowl, and the development of programs by Research and Development, contribute significantly to improving waterfowl management. In addition to cooperative wildlife research units at major universities, the Service has five centers that conduct waterfowl research: Alaska Fish and Wildlife Research Center, National Wetlands Research Center, National Wildlife

Health Research Center, Northern Prairie Wildlife Research Center, and Patuxent Wildlife Research Center.

The Swans

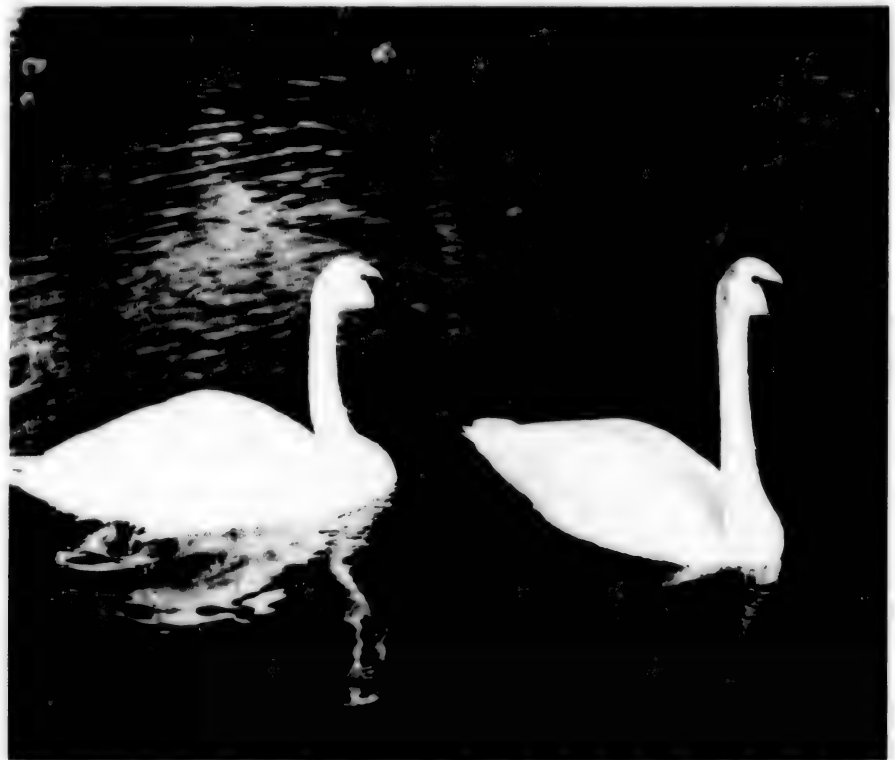
Biologists in several Midwestern, Rocky Mountain, and Western States are trying to reintroduce trumpeter swans to the preferred habitats from which they have been extirpated. A second species, the tundra swan, elicits strong support from waterfowlers and birders during its annual sojourn from breeding areas in Alaska and elsewhere in the Arctic to wintering grounds in Chesapeake Bay and more southern States. Service researchers are studying both species.

Rocky Mountain Trumpeters

Although the trumpeter swans in the Rocky Mountain population numbered fewer than 100 adults in the early 1900's, the population now numbers more than 1,200 birds—because of protection and management. Widespread recovery, however, is not yet expected. Biologists at the Montana Cooperative Wildlife Research Unit studied the history and biology of the population and developed recommendations to manage the species.

The Rocky Mountain population has two subpopulations—one breeds and winters in the tri-state area (Idaho, Montana, and Wyoming) of Yellowstone country and another winters in the tri-state area but breeds in west-central Canada. This pattern probably exists today because the few swans that survived into the 1900's shared the tradition of wintering on the scattered and isolated geothermal waters of the tri-state area. Swan families with traditions of wintering in other locations seemingly were extirpated.

Trumpeter swans, once considered a candidate for protection, thrive in Alaska, but may be declining in the Greater Yellowstone ecosystem.



The tri-state area, however, provides only marginal wintering habitat for trumpeter swans. The swans that breed in Canada leave the tri-state area in early spring and migrate northward to areas with mild temperatures and rich food resources. These birds enter the breeding season with adequate nutritional reserves and are highly productive. In contrast, the tri-state area breeders endure continuing severe weather and nutritional hardship during the critical period before nesting. The birds can successfully reproduce only during the earliest and mildest of springs. Thus, the Service's greatest research priority for these birds is to determine how to improve their wintering and breeding distribution.

Geese

Whether we are painting geese on canvas, watching them through binoculars, hunting them, photographing them, or just enjoying listening to them honk as they migrate

through our landscape, geese seem to draw human attention. Geese, particularly Canada geese, are prolific, and managing these birds in urban and rural areas is a new field of research.

Canada Geese in the Atlantic Flyway

Movement and fidelity to wintering areas have important ecological, evolutionary, and management implications for birds. For example, in the 1960's, the number of wintering Canada geese increased in the Chesapeake Bay area and decreased in the Carolinas but in recent years, geese have decreased in the Chesapeake Bay region and increased in the mid-Atlantic region. Perhaps these changes resulted from lower survival of geese that have migrated to more southerly areas, from geese that have moved into newly created habitat in the north (short-stopped), or from changes in both movement and survival.

Biologists from Patuxent Wildlife Research Center and the New York Cooperative Fish and Wildlife Research Unit used multiple-observation data from 28,849 individually coded neck-banded Canada geese in the Atlantic Flyway to estimate probabilities of the geese returning to previous wintering locations or moving to new ones. Two models were developed and programmed to estimate these probabilities. The model that incorporated tradition (or memory) by geese of previous wintering regions fit the data better than the model that did not incorporate such tradition or memory.

Geese had a high probability of moving to and remaining in the Chesapeake Bay. The estimated probability of moving to the Chesapeake Bay area from the mid-Atlantic or from the Carolinas was 3 times and 25 times higher, respectively, than the probability of moving in the opposite direction. Annual changes in the mid-



Researchers extract blood samples from Canada geese for lead level tests at Cape Churchill Wildlife Management Area, Manitoba. *Photo by M. Gillespie.*

winter waterfowl survey by the Service did not reflect annual changes in movement probabilities but did reflect regional changes in survival rates. However, more geese from the Carolinas seemed to be wintering in more northerly locations in subsequent winters.

Arctic-nesting Geese

Geese nesting in certain areas of Alaska are at great risk: the numbers of cackling Canada, dusky Canada, emperor, white-fronted, and brant geese have all plummeted. Many in-depth Service studies are trying to identify the causes of these declines, reverse them, and identify and evaluate new threats to these and other populations. For example, Alaska Fish and Wildlife Research Center biologists are studying the nesting ecology, habitat requirements, annual production, and population size of nesting geese on the Yukon-Kuskokwim Delta.

Predation, these biologists found, seems to have a direct effect on habitat selection by geese: microhabitat structure between nest sites of emperor and cackling Canada geese was markedly different. For example, emperor geese, the larger of the two species, chose sites that helped conceal them from avian predators such as gulls, while cackling Canada geese selected sites that helped them avoid mammalian predators such as foxes. The nests of emperor geese were most successful when these birds selected nest sites with denser and taller vegetation than that in surrounding areas. In addition, amount and duration of snow cover, drainage patterns, and presence or absence of islands influence nest site selection and, ultimately, distribution and abundance of geese.

The techniques for counting nesting black brant by remote sensing were improved. Analysis of high-quality, standard color-infrared aerial

photography indicated a high correlation between counts of birds from photographs and counts on the ground. Summer field tests of two aerial video systems to count nesting brant on sample plots had promising results. Although standard aerial photography techniques offer high-quality images of nesting brant, the cost is high and the time to count brant from prints is lengthy. By comparison, video images of nesting brant, although initially not as high quality as still photography, can be computer-enhanced to improve visibility of brant on nests. Automated image-scanning devices can provide accurate counts of colonially nesting geese. Preliminary analyses of video data indicate that this technique may be practical and cost-effective for monitoring the status of large colonies of geese and aggregations of seabirds.

Black brant outfitted with radio transmitter for telemetry study on Alaska nesting grounds.



Lead Levels in Geese

From 1986 to 1989, the National Wildlife Health Research Center and the Idaho Cooperative Fish and Wildlife Research Unit and the Wisconsin Cooperative Wildlife Research Unit collected more than 7,000 blood samples from the Eastern Prairie population of Canada geese. They used these samples to determine rates of lead exposure on nesting, staging, and wintering areas. Information from band returns and neck collar reobservations served to determine survival rates of lead-exposed geese. Preliminary results showed a marked decrease in blood lead levels when geese were in pristine habitats or in areas with compulsory use of steel shot by hunters, and a reverse trend for geese that staged or wintered in areas contaminated by lead shot.

White-fronted Geese in the Southwest

In the past 20 years, the Pacific greater white-fronted goose population has declined precipitously—from 500,000 to 100,000 individuals. In 1987, Northern Prairie Wildlife Research Center biologists began a radio telemetry study to examine habitat use, migration, and survival of these geese during winter. These biologists examined the

availability of winter habitats through aerial surveys in the Sacramento Valley and ground surveys in the Klamath River basin (both in California). Researchers found that waste grain abundance decreased greatly when fields were harvested and plowed through the winter; this, in turn, altered feeding behavior of the geese.

White-fronted geese that were marked in the Bristol Bay Lowlands of southwest Alaska had a markedly different migration pattern and used a different wintering area than geese that were marked on the Yukon Delta. Most geese marked in the Bristol Bay Lowlands migrated through California in September and wintered in Chihuahua, Mexico. Geese marked in the Yukon Delta, however, migrated to California in October and remained in California's Central Valley throughout the winter. Survival of adult female geese in California was estimated at 78% ($\pm 11\%$) between mid-November and May. Survival rates of white-fronted geese in Mexico are not known.

The Dabblers

The dabblers include the ducks most familiar to hunters and bird-watchers: wood ducks, American black ducks, mallards, northern

pintails, blue-winged teal, northern shovelers, and others. Although much remains to be learned, research has been more comprehensive on mallards than on any other waterfowl species on the continent.

Bottomland Hardwood Habitat Restoration

Bottomland hardwood forests in the lower Mississippi Valley provide good habitat for wintering waterfowl, especially mallards and wood ducks. Unfortunately, more than 80% of the forest present in the lower Mississippi Valley during colonial times has been cleared. Researchers at the National Wetlands Research Center have been actively involved in the Service's efforts to restore this threatened habitat type.

In one recently completed study, center scientists compared two methods for reestablishing bottomland oak species (direct-seeding and planting of seedlings) currently being used on the Yazoo National Wildlife Refuge in west-central Mississippi. The results indicated that both methods can produce acceptable bottomland hardwood habitat, but that planted seedlings usually survive better and initially grow faster than direct-seeded acorns.

These results may be especially important to the Service's efforts to promote the Conservation Reserve Program among farmers. Because participating farmers who plant seedlings are likely to have more and bigger trees, they may be less inclined to convert reforested fields back to crop production at the end of their 10-year contracts than those who used direct-seeding. These results may also prove to be important in helping develop mitigation success criteria for forested wetlands.

To further support forest restoration efforts, the National Wetlands Research Center produced an extension bulletin for use by private landowners and an annotated bibliography for use by refuge and Fish and Wildlife Enhancement personnel. Other ongoing efforts include preparation of a comprehensive manual on restoration of bottomland hardwood forests and field trials with noncommercial tree and shrub species.

American Black Ducks in New Jersey

Habitat use, nutrient reserve dynamics, and food habits of American black ducks along coastal New Jersey were investigated by biologists with the New York Cooperative Fish and Wildlife Research Unit during the winters of 1983–84 through 1985–86. Daily movement patterns were monitored each winter and determined for 34–58 radio-equipped females. Time of day and ice cover were the most important factors affecting the ducks' habitat use: ducks used refuge impoundments predominantly during the day and salt marshes at night and during frozen conditions. During hunting periods, habitat use was restricted to sanctuary areas in refuges.

Diurnal movements were similar to nocturnal movements and averaged between 0.2–0.4 miles over the course of the winter. Mean home range size for the wintering period was 23.6 ($\pm$ 3.5) square miles. Juvenile females of below median body condition used salt marshes more and refuge impoundments less than juveniles above median body condition or than adults. The potential influence of radio transmitters on free-ranging black ducks was also evaluated.

Researchers collected 69 female black ducks during the winters of 1984–85 and 1985–86 to evaluate changes in carcass composition. Total carcass fat declined 6–11% over

the wintering period, and changes in carcass protein (ash-free lean dry weight) occurred only during the most stressful period. These results suggest that the use of body protein depends upon duration of ice cover and food availability. Juveniles had lower fat and protein levels than adults, although changes in these reserves over the winter were similar between age groups. Indices for assessing body condition by body weight, morphological measurements, percent water, abdominal fat, and plasma (blood) chemistries were evaluated.

Food habits were determined by examination of esophageal and proventricular contents from 40 black ducks. Salt marsh snails were the primary food; they made up 64% of the total diet. However, ice-covered marshes forced birds to rely on foods such as scuds, clams, killifish, and sea lettuce from mud flats and tidal creeks.

Nonhunting Mortality in California

Although we know that migratory waterfowl in California are subject to many diseases, contaminants, and predators, the relative importance of various mortality sources and their effect on waterfowl populations are still unknown. Data from necropsies of carcasses found in the field may be biased because of factors influencing mortality from predation and chronic diseases, including lead poisoning. Because of insufficient information on waterfowl populations at risk, mortality rates cannot often be determined. To help monitor mortality, researchers are using sentinel birds—with a known disease history—restricted to a certain area by wing clipping and cages or pens. Sentinel birds used to monitor mortality can overcome some of the problems listed previously because biologists can keep threatened pop-

ulations constant, and calculate reliable cause-specific mortality rates and comparative risk.

In studies by biologists from the National Wildlife Health Research Center, mortality causes were determined in sick and dead migratory waterfowl and sentinel mallards at Sacramento National Wildlife Refuge during 1986–89. The most frequent cause (81%) of nonhunting mortality in wild birds was avian botulism, followed by avian cholera as the second most frequent diagnosis (10% of carcasses). Other diseases in wild birds included lead poisoning (7%) and avian tuberculosis (1%). Among sentinel mallards, avian botulism was also the most frequent cause of death (41%); lead poisoning was the second most frequent (23%) cause, followed by predation (17%), and avian cholera (3%).

Mallard Band Recoveries

Leg band reporting rate is the probability that hunters who shoot and retrieve banded birds will of their own volition report the band numbers to the Service's Bird Banding Lab. Unlike many uses of band recovery data, inferences about harvest rates (proportion of birds shot) require estimates of band reporting. In 1987, biologists from the Office of Migratory Bird Management and the Patuxent Wildlife Research Center began a reward band study designed to estimate reporting rates and investigate potential geographic variations in these rates. In the first stage of the study, adult male mallards were banded in the summer of 1987 with reward bands of different dollar values (\$0–\$400) to determine the lowest dollar value that would yield a reporting rate approaching 1.0. Recovery rates of the different groups of reward bands indicated that somewhere between \$50 and \$100 were required to yield a reporting rate near 1.0. Thus, biologists recommended that \$100 reward bands be used in

reporting-rate studies in the next few years.

The reporting rate of standard bands (those with no dollar value for return) was estimated at 0.32. Although reward bands with dollar values less than \$100 should not be used in future studies of band reporting rates, small dollar values (\$5 and \$10) did produce reporting rates nearly twice as high as those of standard bands. In special studies to estimate such quantities as annual survival rates from band recovery data, reward bands with small dollar values could be used as a way to increase reporting rates and, therefore, precision of estimates. Researchers developed a model to predict reporting rate as a function of reward band dollar value for possible use in such special studies.

The second stage of the collaborative reporting-rate study involved banding 6,500 mallards with \$100 reward bands and 20,000 mallards with control bands (no monetary reward) at breeding grounds throughout North America in 1988. Recoveries from these bandings are being used to test hypotheses about geographic variations in reporting rates and to estimate reporting rates for different regions of North America.

Predation Levels at Union Slough

Predation is one of the leading causes of waterfowl nest failures. With this in mind, researchers from the Iowa Cooperative Fish and Wildlife Research Unit and the Union Slough National Wildlife Refuge evaluated the effect of predator removal on nest success and recruitment of ground-nesting waterfowl at the refuge in 1988-89. An earlier study (1984-85) at the refuge had estimated nest success of all ground-nesting ducks at 11.9%, with predation by mammals as the major cause

of mortality for eggs and nesting hens (82% of all nest failures).

In 1988, one full-time trapper set box traps and leg-hold traps from March 6 to July 13 for 7,067 trap-nights. Five red foxes, 111 raccoons, 46 striped skunks, 56 opossums, and 15 domestic cats were caught and removed from the refuge at a rate of 0.033 captures per trap-night. In 1989, a similar trapping program was conducted from March 13 to July 16 for 7,522 trap-nights. Eleven red foxes, 102 raccoons, 45 striped skunks, 43 opossums, 13 house cats, 3 badgers, and 1 mink were captured at a rate of 0.029 captures per trap-night.

Upland nesting cover was searched three times each year, April through July, with a chain-drag and 4-wheel ATV's. Nests were monitored until hatch or termination. In 1988, nest success for all species combined was 17.7% for 261 nests of mallards, blue-winged teal, and northern shovelers. In 1989, nest success for all species combined was 26.5% for 313 nests of mallards, blue-winged teal, northern shovelers, American wigeons, and gadwalls. Overall nest success for 1989 was significantly greater than 1988. However, mammalian predation was still the major cause of nest failure, accounting for 73% of failures in 390 unsuccessful nests. Biologists believe that red foxes were responsible for 24% of all failures.

Based on a mallard nest success of 11.3% and a mean observed mature duckling (Class III) brood size of 6.3 at fledging, mallard recruitment in 1988 was estimated at 0.87 female young fledged per adult female. Based on a nest success of 18.5%, and a brood size of 7.7, mallard recruitment in 1989 was 1.7 female young fledged per adult female.

Protecting Nesting Waterfowl With Electricity

More than 12 times as many waterfowl per acre were hatched on peninsulas from which mammalian predators had been removed and which were protected from mammalian predators by electrical barriers than on nearby peninsulas without barriers. During a 5-year study, biologists from the Northern Prairie Wildlife Research Center recorded 6.1 hatched ducklings per acre and 59% nest success on protected peninsulas. On control sites where waterfowl nests were not protected by fences and where predators had not been removed, 0.5 ducklings hatched per acre and nest success was 15%.

In this study, wire fences with a 1-inch mesh poultry netting were built across the base of experimental peninsulas. The fences were 5.5 feet high and the wire mesh was buried to a depth of 1 foot below ground level. The wire extended 50 to 150 feet into the water and two energized wires were placed 4 feet and 5.5 feet above ground level. Predators were removed from inside fenced sites but not from control sites.

Density of nests for all waterfowl species was 1.04 nests per acre on experimental sites, and 0.17 nests per acre on control sites. Gadwalls were the most numerous nesters, followed by mallards, blue-winged teal, and lesser scaup. Although predation was reduced on experimental peninsulas, it was not eliminated, and hens and nests were lost to raptors, crows, minks, and raccoons.

The average cost of each fence was \$5,964.96, or an annual cost of \$650.18 when amortized over 20 years. Capital cost and maintenance expenses result in an annual cost of \$917.93, or \$5.56 for each hatched duck. The response of nesting ducks to the predator-free environments was rapid-nest numbers



A refuge manager checks the electric current at a predator barrier fence in North Dakota. Such fences help reduce predation on nesting waterfowl. *Photo by J. T. Lokemoen.*

increased the first year after the fences were installed.

The Divers

Diving ducks include canvasbacks—an important species of concern—redheads, ring-necked ducks, and scaup. Research on juvenile mortality and lead poisoning in canvasbacks is now underway in breeding and wintering areas.

Restoration of a Canvasback Lake

Biologists from Northern Prairie Wildlife Research Center, North Dakota State University, and Minnesota Department of Natural Resources jointly investigated the effects of lake management on canvasbacks and other ducks. For much of this century, Lake Christina, a large, shallow lake in west-central Minnesota, served as a staging area

for canvasbacks. However, loss of submerged macrophytes from highly turbid water during the 1950's greatly reduced waterfowl use of Lake Christina. Fish removal in 1965 resulted in a temporary decrease of turbidity, an increase of aquatic plants, and a return of canvasbacks and other ducks. Failure to maintain a balanced fish community, however, caused another decline in water quality, plant loss, and low use by waterfowl through the late 1970's and early 1980's.

Removal of fish in October 1987, and subsequent restocking of Lake Christina with game fish, was followed by dramatic changes in the lake. Clearer water in spring permitted emerging plants to grow to a height where light restriction due to turbid water was not a serious problem. By 1988, and again in 1989, water transparency had increased sufficiently to permit the reestablishment of rooted macrophytes. Waterfowl use, particularly during fall migration, increased dramati-

cally. In October of 1988 and 1989, total waterfowl counts peaked at 57,000 birds, more than 10 times the average peak observed over the previous decade. These staging waterfowl included 3,500 canvasbacks in 1988, and 7,100 in 1989.

Restoration of American Wildcelery in the Great Lakes

Beds of American wildcelery provide food for fish and waterfowl, including canvasbacks. The National Fisheries Research Center—Great Lakes and the Northern Prairie Wildlife Research Center documented the loss of American wildcelery tubers in the Detroit River between 1950 and 1985. In response to this decline, State agencies and duck hunter organizations have restoring American wildcelery beds in Michigan waters by planting tubers in early spring 1988. Researchers the National Fisheries Research Center—Great Lakes, in cooperation with State and private

personnel, evaluated the success of this restoration at two locations in the lower Detroit River where traditional American wildcelery beds once attracted large numbers of migrating waterfowl.

In spring 1988, about 700 bags of tubers, each with an average of five tubers per bag, were planted at two locations in the lower Detroit River. In late September, scuba divers collected planted and natural American wildcelery to determine the success of the planting. One site was completely overgrown with water stargrass and showed no signs of planted or natural growth of American wildcelery. Little stargrass had been observed at this location previously; researchers believe that the failure of American wildcelery and the total dominance of star grass in 1988 was caused by a very warm summer and large fluctuations in water level that favored the opportunistic star grass.

The second site yielded from 1 to 6 new plants per bag. In addition, new plants originating from planted bags yielded 4 to 10 tubers per bag. In total, between 2,800 and 7,000 tubers were produced from the plant-

ing of 700 bags at this one location. Comparison of length and biomass of planted and unplanted American wildcelery indicated similar growth of planted and unplanted rosettes. The success of American wildcelery restoration at the second location is attributed to the site being more uniform in depth, 3-7 feet deeper than the unsuccessful planting location, and protected from high waves by nearby land. This work indicates that restoration of American wildcelery in the lower Detroit River is possible under the proper conditions and could become a useful waterfowl management practice.

Redheads on the Gulf Coast

Despite 30 years of restrictive bag limits, redhead duck populations have not returned to historic levels. In 1987, biologists from the National Wetlands Research Center began investigating whether habitat deterioration on wintering grounds might be one cause of continued low numbers of redheads.

More than 75% of the continental redhead population winters on the Laguna Madre in Texas and the Laguna Madre de Tamaulipas in

Mexico. The investigation confirmed earlier observations that shoalgrass rhizomes are the prime winter food of redheads; shoalgrass, however, had declined profoundly between the 1960's and 1988.

Measurement of underwater light before and after maintenance dredging confirmed earlier speculations that losses of shoalgrass from deeper parts of the laguna result from persistently high levels of turbidity. In shallower areas, large expanses of shoalgrass meadow have been replaced by turtle grass and manatee grass, which are less tolerant of high salinities. The proliferation of these plants followed channel dredging that increased water exchange with the Gulf of Mexico and a rerouting of Rio Grande fresh water to the laguna by floodwater drainage channels after use by municipalities and agriculture.

Redhead access to freshwater ponds (for drinking) adjacent to bay feeding areas seems to be another critical habitat requisite in this region of usually hypersaline embayments. This is not true in the characteristically brackish waters of other wintering areas.

The majority of the continent's redhead population overwinters in the Laguna Madre in Texas and the Laguna Madre de Tamaulipas in Mexico.



Assessments of body condition of redheads showed that expended fat reserves during the breeding season and autumn migration were replenished by the end of winter. Wintering habitat therefore seems to be adequate in quality and quantity for support of the current population of redheads. Whether the habitat will be sufficient to support the typically larger populations of redheads of earlier periods or continue to be sufficient to support current levels of redhead populations (given the continuing trend of both reduced shoalgrass beds and reduced redhead access to freshwater ponds) has yet to be determined.

Cable Cars and Canvasbacks

The San Francisco Bay area, with a human population of 6 million, is the most urbanized estuary in the United States. The Bay, including the Sacramento-San Joaquin River Delta, is also a major wintering area for 700,000 waterfowl in the Pacific Flyway.

In 1987, scientists from the Northern Prairie Wildlife Research Center began examining the San Francisco Bay ecosystem and trying to determine the effects of environmental contaminants on waterfowl populations. To examine the distribution and abundance of waterfowl bay habitats, aerial surveys were conducted between October and April 1988-89 and 1989-90.

More than 160,000 ducks were observed in October and numbers exceeded 260,000 by January. Waterfowl use exceeded 29.8 million bird-days each year. Diving ducks—mostly greater and lesser scaup, surf scoters, and canvasbacks—accounted for 76% of the surveyed waterfowl.

Salt ponds that surround the Bay were used by several duck species and contained 41% of all counted waterfowl. As many as 72% of the canvasbacks were observed in the salt ponds of the north bay.

Migratory Shorebirds

In addition to migratory waterfowl, the Service now recognizes the importance of proper management of other nongame migratory birds, including groups such as shorebirds. While some of the research on shorebirds focuses on specific bird species, other research concentrates on understanding the importance of habitat used during migration for basic biological needs. One critical aspect is the role that inland wetlands play as staging areas for migrating shorebirds.

Status, Distribution, and Biology of Bristle-thighed Curlews: An International Study

Proposed petroleum development over much of the Continental Shelf jeopardizes essential coastal habitat for shorebirds. In this fight, the Alaska Fish and Wildlife Research Center is investigating aspects of the life histories of several Alaskan shorebirds, with an emphasis on threatened bristle-thighed curlew. The bristle-thighed curlew is the only species of curlew whose status is totally unknown. Indeed, the entire world population is thought to number fewer than 7,000 individuals, and little historic data exist for assessing possible changes in the population. However, some biologists suggest that either marked curlew population declines or shifts in the birds' use of wintering habitat (which encompasses all island groups of the central and south Pacific Ocean), have occurred since the early 1900's. Subsistence hunting of the birds on their wintering grounds and in Alaska, exposure to contaminants, and changes in their food resources are thought to have contributed to the declining or shifting population.

In 1988 and 1989, biologists from the Montana Cooperative Wildlife Research Unit, with support from the Alaska Center, studied curlews on Laysan Island in the northwestern Hawaiian Islands chain. Their most exciting discovery was that adult curlews become flightless during molt, a trait previously unknown in shorebirds. From repeated observations of marked individuals, biologists also determined that 350 to 400 curlews spend the fall on Laysan Island. Adults (3 years old or older) migrate to Alaska in early May and return to Laysan Island in July and August. In contrast, most subadults remain on this island throughout the summer. Minimum annual survival from 1988 to 1989 was 80% for adults and 88% for subadults. Ultimately, these study results will be used to formulate a comprehensive management plan for this threatened bird.

Littoral Zone Use by Postbreeding Shorebirds on the Colville River Delta, Alaska

From July through September 1987-88, the Ohio Cooperative Fish and Wildlife Research Unit surveyed density, abundance, and feeding behavior of shorebirds in the Colville River Delta, an area with the most extensive salt marshes and coastal silt barrens along the Central Beaufort Sea. Dunlins and sanderlings dominated the shoreline habitat; all other species of shorebirds concentrated in salt marshes, with semipalmated sandpipers the most common species in the salt marsh. Feeding, to the point of virtual exclusion of all other behaviors, was the dominant activity of all shorebirds. The increase of the abundance of shorebirds with invertebrates, notably midges, demonstrates the dependence of shorebirds on the near-shore and shoreline region of the Colville River Delta.

The Use of Monofilament Lines to Reserve Nesting Habitat for the Common Tern

Breeding populations of the common tern in the lower Great Lakes region have been declining over the past decade. Increased numbers of nesting ring-billed gulls, vegetation succession, and human disturbance are the principal causes for this decline. The ring-billed gull has been particularly disruptive to a small colony of common terns nesting on Oneida Lake in upstate New York. Beginning in Spring 1986, the New York Cooperative Fish and Wildlife Research Unit constructed a simple semi-open canopy of parallel strands of monofilament fishing line to reserve portions of the island for nesting common terns. This strategy has been remarkably effective in limiting access by gulls, but allowing access and successful nesting by the terns. Four years of data reveal that:

- gulls can be eliminated from selected areas and that their total nesting population on Oneida Lake has been reduced from 2,300 pairs to 1,500 pairs;

- common terns readily nest beneath the partial canopy of parallel strands and have increased their chick production and their fledging rate from a low of 0.41 chicks per pair to 0.96 chicks per pair in 4 years;
- one entire island and significant parts of three other islands have been reclaimed to encourage nesting of common terns; and moreover, nesting terns have been reestablished on one island where a large tern colony existed in the early part of this century, but had not been used by these birds since the early 1970's.

Critical Inland Wetlands for Migrating Shorebirds

The wetland complex at Cheyenne Bottoms in central Kansas provides critical habitats for internationally migrating shorebirds that breed in Alaska and winter in Central and South America. As many as 45% of all continental shorebirds and more than 90% of the individuals of 5 species are purported to use the Cheyenne Bottoms as rest areas twice each year. Biologists at the National Ecology Research Center have begun studies on the central Great Plains to evaluate the Chey-

enne Bottoms and surrounding wetlands at the Quivira and Salt Plains national wildlife refuges. Their preliminary findings reveal that the Cheyenne Bottoms is not a singly unique resource but is a critical component in a complex of wetlands that shorebirds need across the plains States. Birds rest at Cheyenne Bottoms but do not accumulate lipid reserves as they do at coastal sites such as Delaware Bay. Rather, the continental migration appears more leisurely, with birds stopping at many areas to forage. Biologists are now expanding their studies to identify those wetland complexes north of Kansas and Oklahoma that are critical for shorebirds to complete their semiannual movements across the continent.

Other studies on inland wetlands include the examination by the Utah Cooperative Fish and Wildlife Research Unit of the Great Salt Lake basin as a staging and production area for migratory shorebirds. As many as 35 species of shorebirds pass through this basin

Numerous small, continental wetlands provide critical habitat for shorebirds migrating across the central Great Plains.
Photo by F. L. Knopf.



during spring and fall migration. Another dozen or so species breed in the basin. A major thrust of this research is to determine temporal and spatial use patterns of the wetlands in the basin by migratory shorebirds. Because of development pressures around the lake, these studies are a priority and were designed to evaluate the importance of the basin at an ecosystem level. Cover maps, prepared by remote sensing, will be used to determine relations between shorebird distribution patterns and landscape mosaics, evaluate the macroinvertebrate prey base for shorebirds, and allow the study of wetland vegetation successional patterns. Much of the work is being conducted in the Bear River National Wildlife Refuge, which is recovering from the effects of prolonged flooding from 1986 to 1988.

Upland Game Birds

Survival and Movement of Translocated Pheasants

This 2-year radiotelemetry project, sponsored by the Missouri Department of Conservation in cooperation with the Missouri Cooperative Fish and Wildlife Research Unit, was designed to investigate survival, movements, habitat use and reproductive activity of a wild pheasant population that had been moved to an unoccupied area in central Missouri. To determine appropriate pheasant stocking levels, 180 ring-necked pheasants (58 males and 122 females) were captured at Squaw Creek National Wildlife Refuge in northwest Missouri and then moved to Franklin Island Wildlife Management Area in central Missouri. About 75% of all hens survived the first week after capture and relocation. Hen survival from release to peak of nesting was 26% in 1988 and 42% in 1989. Survival of hens from

spring to fall was 49% and survival from fall to spring was 86%. Hens were tracked by radio collars and located within 1.9 miles of the release site, with 95% found within 1 mile of the release site. In 1988, the estimated rate of spatial diffusion by the population was a little more than 11 feet per day. Hens established nests about 6/10ths of a mile from the release site. Reproductive success was similar to success by established pheasant populations in Wisconsin.

Habitat Use Patterns of Female Prairie-chickens

Biologists at the Missouri Cooperative Fish and Wildlife Research Unit examined the effect of two different spatial patterns of prairie distribution on movements, home range, habitat use, and reproductive success of greater prairie-chicken hens in Missouri. A population of prairie-chickens that inhabited a mosaic of prairie tracts in intensively cultivated private land was compared with a population of birds in a large, contiguous, but isolated, tract of intensively managed native prairie. In the prairie-agricultural mosaic, home ranges were made up of an array of habitats, although managed native prairie was never strongly preferred. In contrast, in the prairie island area, birds preferred managed native prairie in all seasons. Data indicate that large prairie tracts are more effective than smaller, scattered ones in attracting female prairie-chickens. These results suggest that nesting females cannot be "packed" onto small prai-

rie tracts to make these parcels intensive prairie-chicken production areas. Most reproduction on the prairie-agricultural mosaic occurred in cultivated fields, where nests and broods are vulnerable to agricultural practices. Because large prairies do not exist in Missouri, agricultural lands interspersed in native prairie may be the only management option. Scattered tracts of native prairie seemingly do not attract female prairie-chickens.

Survival of Woodcock

In 1986, the northeast research group of the Patuxent Wildlife Research Center began a 4-year study of survival in American woodcock at Mooschohorn National Wildlife Refuge near Calais, Maine. The study evaluated responses of woodcock to long-term, intensive habitat improvements on the refuge by assessing the survival rates of breeding males and females and their nests and broods.

After a pilot study in 1986, 50 male and 25 female woodcock were captured and fitted with radio transmitters in each of the 3 succeeding years and monitored from early April to mid-June. Survival rates for the April-June period were estimated as listed below.

Survival rates of males were variable among years—many males were killed by predators in 1986 and harsh spring weather in 1989. Survival rates of females were less variable, but data for many females were incomplete because the birds disap-

Year	Male			Female		
	Number	Number died	Survival rate	Number	Number died	Survival rate
1986	24	6	0.469	11	2	0.667
1987	54	8	0.757	31	1	0.833
1988	51	3	0.927	27	5	0.658
1989	46	9	0.685	20	1	0.875

peared from the study area after nest loss. Females that left the study area frequently nested again, often as far as 10 miles from the original nest site.

Nongame Wildlife

The Fish and Wildlife Service manages all migratory bird species in North America, most of which are classified as nongame. Management consists of monitoring the abundance of birds and determining species-specific habitat requirements. A trend in research is to combine field observations with model building to gain the ability to predict change. The realization that human disturbance affects not only particularly sensitive species but also an entire community of species has advanced application of a broader, more regional approach in nongame wildlife management. For example, Geographic Information Systems, which store data such as topography, vegetation, and hydrology, allow scientists to develop detailed maps on a variety of information, including a species' habitat use and its response to habitat change.

Establishing the Data Base With Status Reports

An important goal of the Service is to maintain or increase population levels of migratory birds. Species that demonstrate unstable or decreasing populations in any significant portion of their range are identified, causes for the problem are identified, and management guidelines are developed. This type of preventive strategy is more cost-effective than the full-scale recovery necessary after a species has to be listed as endangered or threatened. In keeping with this philosophy, the Missouri Cooperative Fish and Wild-

life Research Unit developed status reports in 1989 for 14 species of nongame birds with unstable or decreasing populations. These reports included information on distribution, population status and trends, life history, limiting factors, and research needs and management.

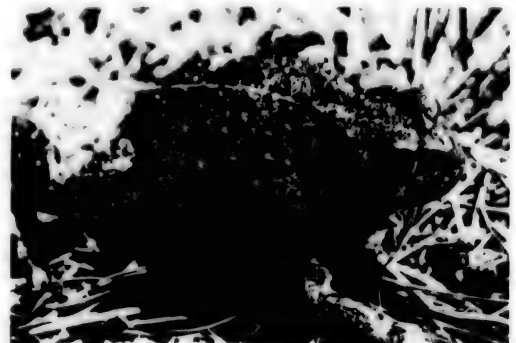
Counts, however, are only useful if they truly reflect a species' status. To improve accuracy and to assess the usefulness of using counts of migrating raptors to monitor raptor population trends, the Patuxent Wildlife Research Center and Virginia Cooperative Fish and Wildlife Research Unit compared actual counts of migrating raptors with nesting surveys of well-studied species. The results revealed that peregrine falcons, bald eagles, and ospreys have increased in numbers, but no consistent trend could be detected for kestrels. Thus, counts of migrant raptors appear to be a useful and economical method for

detecting long-term trends in species across regions, particularly for species that cannot otherwise be easily surveyed.

Declining Amphibian Populations in the Rocky Mountains

In a 1986 to 1989 study, zoologists from the National Ecology Research Center surveyed amphibians in the Rocky Mountains of northern Colorado and southern Wyoming as part of a joint study by the U.S. Fish and Wildlife Service, the U.S. Forest Service, and the National Park Service. Alarming, the researchers discovered that northern leopard frogs were present at only 12% of their historically known localities, and boreal toads were present at only 17% of their historically known localities. Chorus frogs suffered a catastrophic decline in one population that has been monitored since

Boreal toad, an amphibian that shows continuing declines in the Rocky Mountain region. *Photo by S. Corn.*



Boreal chorus frog. Herpetologists from the National Ecology Research Center have studied the population dynamics in a Colorado site since 1961. *Photo by S. Corn.*

1961, but regionally this species was observed in 64% of historically known localities. Tiger salamanders and wood frogs were present at 45% and 69% of known localities, respectively. Acid-neutralizing capacity, pH, specific conductivity, and cation concentrations in water at amphibian localities were negatively correlated with elevation. However, in mountain ponds and lakes, pH was rarely less than 6.0 during the amphibian breeding season. The lethal pH level for the species studied ranged from 4.2 to 4.7 indicating that acid precipitation probably was not a major cause of the decline of leopard frogs and boreal toads. These declines are concurrent with declines of several species of frogs and toads in Arizona, California, New Mexico, Oregon, Utah, and Washington. The causes for these declines are being sought.

National Collection of Mammals

The Mammal Collection at the National Museum of Natural History in Washington, D.C., consists of more than 600,000 specimens, about half of which belong to the U.S. Fish and Wildlife Service. The museum received and catalogued more than 2,513 specimens, including holotypes of 10 mammals new to science, and added them to the electronic data base for the collection. An additional 15,000 mammal specimens were curated or installed during fiscal year 1989 and fiscal year 1990. Various institutions borrowed 1,228 specimens for research.

Life History Investigations

Although several national wildlife refuges provide nesting habitats for seabirds, researchers know little about the areas from which these birds obtain food for themselves and

their young. Many species fly long distances to fish. In collaboration with the Sea and Sky Foundation, University of Miami, National Audubon Society, the Caribbean National Wildlife Refuge, the Seal Island National Wildlife Refuge, and the Patuxent Wildlife Research Center, researchers developed radio-marking and aerial tracking techniques to study white-tailed tropicbirds in Puerto Rico and Atlantic puffins in Maine. Biologists followed the white-tailed tropicbirds to a deepwater foraging area about 44 miles from the nest colony. Foraging trips usually lasted about 24 hours and the adults brought the young about 1½ ounces of fish and squid. All white-tailed tropicbirds flew to one general foraging area, upwind from their nest colony. In contrast, Atlantic puffins on the coast of Maine flew an average of about 13 miles to fish. Each bird foraged in a different area around the islands they visited.

Researchers radio-tracked white-tailed tropicbirds to deepwater foraging areas and to the Sargasso Sea where the birds are believed to spend the nonbreeding season. These birds may fly as much as 44 miles from their nesting colony to a foraging area.
Photo by M. Fuller.



Body Mass Dynamics and Survival of Nongame Birds in Winter

For the past 10 winters, nongame birds were captured and banded at a feeding station at Patuxent Wildlife Research Center. Survival probabilities were estimated for several species and all birds were weighed and subcutaneous fat measured. Researchers found that ground-foraging species were fatter than tree-foraging species throughout the winter. The amount of fat and weight of ground-foragers were inversely correlated with temperatures and positively correlated with precipitation, particularly snow depth. Year-round resident species had higher overwinter survival probabilities than did winter residents.

The Desert Sucker in Southern Arizona Streams

Populations of desert sucker, a fish species native to Arizona, have declined in the last decade. To determine the causes of the population decline, seasonal feeding patterns, gonadal development, duration of spawning season, and habitat use of these fish were documented by biologists of the Arizona Cooperative Fish and Wildlife Research Unit. Habitat loss, the biologists found, was the primary reason for the decline. Desert suckers were numerous in pools (20 inches deep and deeper) associated with undercut banks, overhanging brush, or roots. Desert sucker populations will probably continue to decline unless habitat protection measures are implemented.

Model Development

To provide information for wolf reintroduction efforts, biologists modeled and studied the potential effects of wolf predation on mule deer and elk populations between

the East Front of Glacier National Park and the Dearborn River drainage in Montana. These biologists estimated that 50 wolves could inhabit the area if hunter harvest of elk cows and calves would be reduced by half, and even more wolves could be sus-



In an effort to determine habitat preferences for snapping turtles, a researcher measures and marks an adult snapping turtle near Laurel, Maryland. Photo by B. Reynolds.



An adult male snapping turtle is fitted with a temperature-sensitive radio transmitter before release at the capture site. Photo by S. Gotte.

tained if antlerless hunting would not be permitted. Scientists projected that a population of 50 wolves would curtail increases of mule deer at population levels of 6,000 but not 9,000. When wolves are reintroduced into the area, the mule deer population can probably support

30-45 wolves and a hunter harvest of more than 500 animals.

Several research centers are evaluating Habitat Suitability Index (HSI) models to improve our assessments of habitat quality. For example, investigators at Patuxent examined variables used in the pileated woodpecker model to determine the accuracy of habitat characteristic indicators for old-growth habitats that these birds prefer in eastern Maryland. The study revealed that pileated woodpeckers were most abundant in forests with the highest density of large snags and large trees and chose larger-diameter trees for night roosts. The model accurately reflects these preferences.

A concurrent study was conducted by Missouri Cooperative Fish and Wildlife Research Unit biologists. In this study, measurements of habitat features that correlated with pileated woodpecker densities on 16 study areas were used as parameters in a new pattern-recognition (PATREC) model for this species. The percentage of an area covered by floodplain and pole timber, and densities of trees greater than or equal to 12 inches diameter at breast height (dbh) and snags greater than or equal to 21 inches dbh were positively related to pileated woodpecker densities. These results suggest that maintenance of mature forest stands on floodplains promotes the increase of woodpecker densities.

The National Ecology Research Center developed an HSI model for the snapping turtle, an abundant and important component of most wetland habitats in eastern North America. A large population of snapping turtles in two different kinds of habitat on Service property at the Patuxent Wildlife Research Center near Laurel, Maryland, were studied during 1988 and 1989. Biologists captured 80 different individuals 93 times in 1,200 trap/days in five different ponds, and placed radio transmitters on 11 turtles. Turtle biomass and



In contrast to the snags (standing dead trees) of coniferous forests, large dead limbs in living trees allow many birds to excavate cavities in deciduous forests. *Photo by F. L. Knopf.*

density were greatest in ponds with the deepest organic substrate, the most submerged woody structure, and vegetation dominated by submergent plants. Turtles were less numerous in ponds with the shallowest organic substrate, no submerged woody structure, and substantial amounts of emergent vegetation.

Identifying Key Habitat Types

The Missouri Cooperative Fish and Wildlife Research Unit located nests of accipiters throughout the forested areas of Missouri to determine reproductive characteristics of these birds, with particular emphasis on nest site habitats. Ninety-four percent of 17 sharp-shinned hawk nests were in pine stands, 77% of 43 Cooper's hawk nests were in pine

stands, and 23% in oak-hickory stands. Reoccupancy rate for accipiter nest sites was 70%. The vegetative structure of pine stands that both species selected was similar, but sharp-shinned hawks nested in an earlier successional stage. Management for these species in pine stands should be directed toward providing stands with a high percent of canopy closure and basal area.

Biologists of the Alabama Cooperative Fish and Wildlife Research Unit studied gray squirrel populations in even-aged pine, mixed pine-hardwood, and hardwood habitats in southern Alabama. Data on 603 squirrels during 2 years indicated that mixed pine-hardwood habitat supported squirrel populations as well as hardwoods, but squirrel populations were low in even-aged pine habitat. Moderately open understories with a

denser shrub-crown component may be important determinants of gray squirrel abundance. Because hardwood stringers (narrow bands of hardwoods along small, often intermittent streams) were heavily used by radio-collared squirrels in both mixed pine-hardwood and even-aged pine habitats, these areas should be included in forest management plans.

Many birds of native forests are dependent upon snags—dead, standing trees—for nesting and roosting cavities. However, trees in cottonwood floodplains of the western Great Plains, especially in the sandy alluvial deposits along major rivers, generally fall shortly after death. Consequently, habitat evaluation for development of management plans may underrate habitat

quality for cavity-dependent species if estimates of cavity abundance exclude living trees and are based only on cavity abundance in snags. Biologists at the National Ecology Research Center demonstrated that the rich cavity-nesting bird fauna in cottonwood floodplains is dependent upon large dead limbs in old, live trees. These findings have drawn attention to similar patterns in other deciduous forest associations on the continent and have fostered new and distinctly different prescriptions for management of cavity-nesting birds in deciduous forests.

Habitat Change and Species Response

In Arizona, large amounts of water continue to be diverted from the Verde River and Wet Beaver Creek for irrigation of agricultural crops and pastures. Service biologists with the Arizona Cooperative Fish and Wildlife Research Unit responded to concerns by the Arizona

Game and Fish Department that many fish (including some threatened and endangered species) might enter these irrigation canals, which do not have structures that keep out fish. Thus these biologists sampled fish in two irrigation canals to determine habitat suitability for fish and relative abundance of fish. Only two introduced species, red shiner and smallmouth bass, entered the canals in accountable numbers; generally these fish did not survive in the canals because of pool desiccation and predation.

Researchers from the Oklahoma Cooperative Fish and Wildlife Research Unit, in cooperation with the departments of Zoology and Agronomy at Oklahoma State University, recently completed a 2-year study on the use of tebuthiuron- and triclopyr-modified Cross Timber habitat by songbirds and woodpeckers in central Oklahoma. After 5-6 years of application of herbicides, songbird and woodpecker populations were more diverse and

numerous in fall and winter forests that had been treated (treatment) with herbicides than in forests that had not been treated with herbicides (control). Total breeding bird densities did not differ between control and treatment, but species composition differed among treatments. Several interior woodland species were restricted to unmodified Cross Timber habitat. Amount of edge, habitat structure, and possibly food availability resulted in differences in species composition on each treatment.

Nongame Bird Responses to Cattle Grazing in Riparian Habitats

Livestock grazing has degraded riparian vegetation in the western United States. Studies by biologists at the National Ecology Research Center revealed that not all bird species respond similarly to pastures, especially willow-shrub communities. The common bird species that breed in a willow-shrub community can be

Traditionally, cattle have been grazed in lake or riverine ecosystems such as that at the Arapaho National Wildlife Refuge in Colorado. In western states, these woody communities provide habitats for many nongame bird species. The presence and abundance of bird species with narrower ecological tolerance for disturbance can be an indicator for management of these riparian areas. *Photo by F. L. Knopf.*

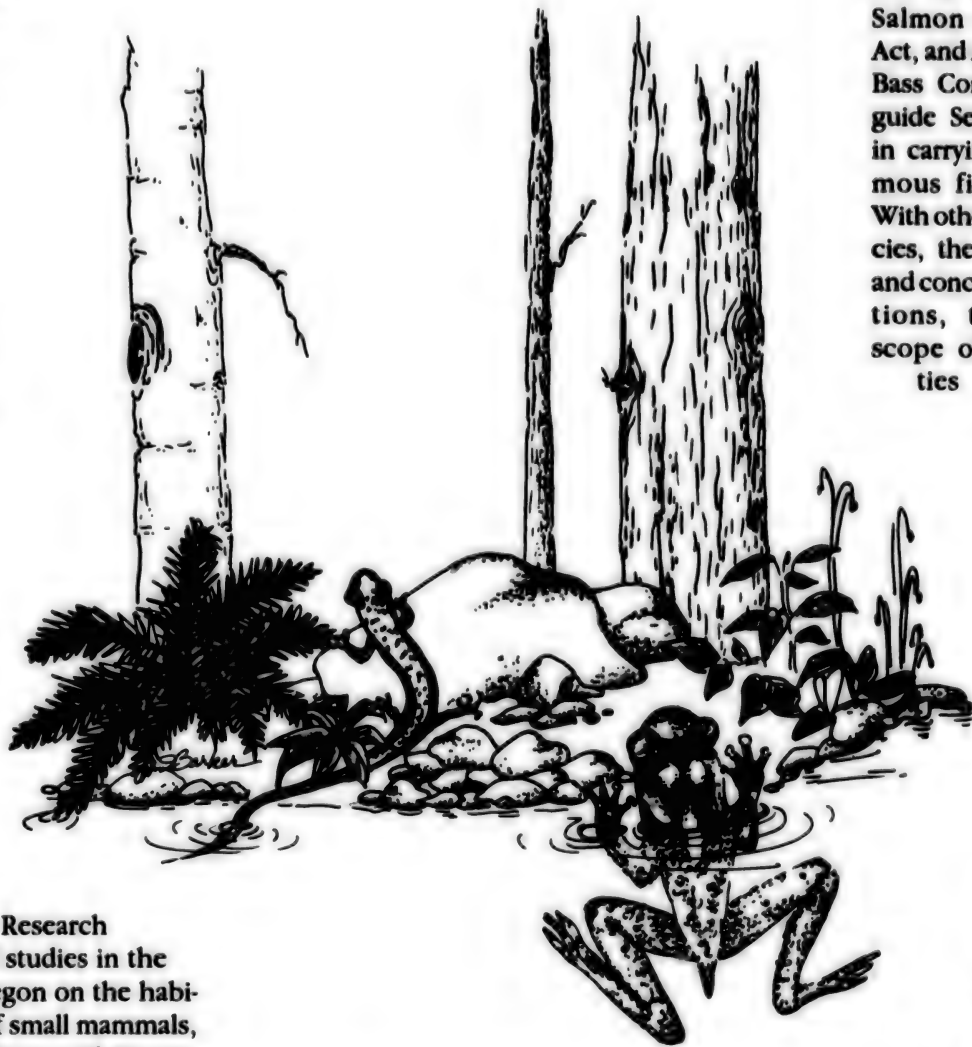


placed in one of three categories or guilds. On the Arapaho National Wildlife Refuge in Colorado, three species of birds showed little response to grazing and were common in an area irrespective of seasonal grazing practices. One species group had narrower ecological tolerance for disturbance and occurred in lowest numbers. Another group included birds whose response to grazing was intermediate. The presence, and abundance of bird species with narrower ecological tolerance for disturbance were proposed as valid indicators for management of riparian bird habitat.

Effects of Timber Harvest on Aquatic Amphibians in the Pacific Northwest

Zoologists from the National Ecology Research Center conducted studies in the coast range of Oregon on the habitat relationships of small mammals, terrestrial amphibians, and stream-dwelling amphibians in a seral sequence—clearcut to old growth—of Douglas-fir forests from 1983 to 1985. The work was funded by the Forest Service and Bureau of Land Management. Stream amphibians were the dominant vertebrates in headwaters of streams. Species richness, density, and biomass of

tailed frogs, Pacific giant salamanders, Olympic salamanders, and Dunn's salamanders were highest in streams in uncut forests. Eleven streams in logged stands had one or no aquatic amphibian species present, and only one contained all four species.



Anadromous Fishes

The anadromous fish resources of the United States have been the responsibility of the Service since establishment of the position of Commissioner of Fish and Fisheries

by Congress in 1871. Service involvement has continued unabated since the first salmon hatchery was established in California on the McCloud River in 1872. Numerous statutory mandates, including the Anadromous Fish Conservation Act, Fish and Wildlife Act of 1956, Pacific Salmon Treaty of 1985, Salmon and

Steelhead Conservation Act, Great Lakes Fishery Act of 1956, Atlantic Salmon Conservation Act, and Atlantic Striped Bass Conservation Act guide Service activities in carrying out anadromous fish programs. With other Federal agencies, the States, tribes, and concerned organizations, the Service's scope of responsibilities for anadromous fish stewardship are

to (1) aid restoration of depleted, nationally significant fishery resources; (2) seek and provide mitigation for impaired fisheries from Federal water-related development; (3) assist with management of fishery resources on Federal (primarily Service) and Native American land; and (4) maintain Federal leadership in scientific management of national fishery resources. To these ends, the Service's research centers and cooperative fish and wildlife research units con-

duct research projects to assist managers in better understanding the many aspects of the anadromous fish resources.

Physiology and Stress

The fisheries agencies and tribes involved in the Columbia River Basin Fish and Wildlife Program of the Northwest Power Planning Council have emphasized the importance of improving the efficiency and effectiveness of existing hatcheries through release of better-quality smolts. The National Fisheries Research Center—Seattle has entered into a long-term cooperative study, funded by the Bonneville Power Administration, to develop a sensitive, reliable index for assessing fish health, physiological quality, and readiness to migrate at time of release. Fish quality indices at Federal and State spring chinook salmon hatcheries are being monitored throughout the rearing cycle and compared with performance indicators, including smolt survival through the returning adult stage. Work at six hatcheries produced an array of spring chinook salmon smolts that differ in age, genetic makeup, size, health, and physiological development. Data analysis is still incomplete, but tentative conclusions are that smolt quality at release dams correlates with performance and survival and that quality indices are affected by hatchery conditions.

The anadromous fish runs of the Chehalis River—Grays Harbor drainage in Washington State are second only to those of the Columbia River basin. However, smolts migrating from rivers that flow into undeveloped areas of Grays Harbor consistently experience substantial estuarine mortality. As many as 40,000 adult coho salmon may be lost to the fishery each year. Because both hatchery and wild smolts are affected, the increased mortality may be due to water-quality problems

from municipal and industrial effluent discharges rather than to an intrinsically lower survival rate of Chehalis River stocks. In an effort to resolve this smolt mortality problem, Seattle researchers worked as part of a team to document the effects of industrial and municipal effluents on the smoltification and early marine survival of juvenile coho salmon. Results indicate only minor direct effect of freshwater effluent exposure on the actual seawater growth and survival of exposed smolts. Therefore, effluent exposure alone may be only indirectly involved in the coho salmon smolt mortality in the lower Chehalis River.

The Seattle center's Columbia River Field Station is continuing a study to determine the role of smoltification and bacterial kidney disease in migratory behavior of juvenile salmonids. Juvenile salmon and steelhead trout historically used flows of the spring freshet to migrate seaward in the Columbia River basin. The migration rates are seemingly highest when the fish have a relatively low prevalence of bacterial kidney disease and are in an advanced state of smoltification. These factors are affected by the condition of fish when they are released from the national fish hatcheries and by subsequent in-river smoltification, so disease and physiological state have become serious management concerns when groups of marked fish are used to follow the progress of the migration. However, migration rates have slowed and survival has decreased because of the slow water velocities from reservoirs of main-stem hydroelectric dams. To increase survival of juvenile salmonids, the Service participates in managing the water budget, a volume of stored water used in spring to enhance the environmental conditions during the seaward migration.

Population and Restoration Studies

In cooperation with the Service's Alaska region and State biologists, the Alaska Fish and Wildlife Research Center began studies in 1989 to determine the spawning distribution of sockeye salmon at Tustumena Lake on the Kenai National Wildlife Refuge, particularly along the shoreline; identify the peak emergence and out-migration timing of juveniles from tributaries into the lake and how these events correlate with environmental variables to predict subsequent survival; and determine if differences exist between the growth and survivability of wild and hatchery-reared juveniles at Tustumena Lake. The Alaska Department of Fish and Game has augmented natural stocks of sockeye salmon in the lake with hatchery-incubated fingerlings since 1976. As many as 35% of the 200 Tustumena sockeye tagged with radio transmitters had spawned in shoreline areas of the lake—an indication that the drainage is not as spawning-limited as previously thought. In addition to new juvenile studies, radio-tracking activities will continue.

The National Fisheries Research Center—Gainesville and the University of Florida Cooperative Fish and Wildlife Research Unit began studies in 1988 to determine the life history, food, movement, and seasonal abundance of the Gulf of Mexico subspecies of Atlantic sturgeon in the Suwannee River, Florida. The Suwannee is believed to support the largest and possibly the only remaining viable spawning population of the Gulf sturgeon, which is a candidate species for listing as threatened under the Endangered Species Act. Knowledge gained in the Suwannee River will help restore and manage sturgeon in other Gulf rivers. The Gainesville center also assisted the Panama City, Florida Fisheries



Transferring Atlantic salmon parr to stock in small nursery streams in Maine. Research indicated that brook trout shift habitat positions when Atlantic salmon are present. *Photo by J. Moring.*

Assistance Office with artificial spawning of Gulf sturgeons at temporary hatchery facilities near the mouth of the Suwannee River. This is the first recorded attempt to culture this fish. Resulting progeny were used in food and other life-requirement studies at the center.

The newly established Northeast Anadromous Fish Research Laboratory in Turner Falls, Massachusetts, became operational in January 1990. Its mission is to conduct research on anadromous fish and river passage mitigation, and to develop life history data to permit anadromous fish population management on the east coast. Studies have begun on mortality of juvenile river herring, passage of Atlantic salmon smolt at hydroturbine facilities, life history of the shortnose sturgeon, and downriver migration of American shad. Researchers at the laboratory recently determined the migratory pattern of the shortnose sturgeon, and are using

Development of culture methods for the Gulf sturgeon may be the only way the species can be restored in its native range.





Personnel of the National Fisheries Research Center—Gainesville developed a method to artificially raise Gulf sturgeon.

this information to develop a river passage management plan for this species.

Hatchery stocks of steelhead typically spawn earlier in the season than comparable wild stocks. In out-planting programs—where hatchery fish are released away from the hatchery so that they will return to the area of release, spawn naturally, and thereby supplement natural production—such early spawning may have undesirable effects on the production and genetic composition of the naturally spawning population. The Idaho Cooperative Fish and Wildlife Research Unit, supported by Seattle researchers, compared upstream movement, spawning behavior, and egg-to-fry survival in cold and warm water. First estimates show good juvenile survival in both cold and warm water.

The California Cooperative Fishery Research Unit completed a 2-year study on the loss of fall-run chinook salmon fry at a spawning channel adjacent to the Sacramento River. At mitigation facilities—such as spawning channels and fish bypass and screening facilities—rotary drum screens are used to direct fish. The efficiency of the screens is low, especially for directing fry, and many fry roll over the screens and escape into irrigation canals or other undesirable habitat. Up to 20% of fry produced were lost from the spawning channels, mainly at night and during periods of high turbidity. Most escaped fry were less than 1.5 inches long and about 10% were yolk-sac fry. In both study years, migration peaked in January and February, and was usually associated with storms, which increased turbidity. Preliminary results showed bright lights over the screen complex had a dampening effect on loss of fry from the channel unless turbidity was high.

The Colorado Cooperative Fish and Wildlife Research Unit produced a monograph on the theory of statistical design and analysis of experiments to estimate salmonid survival rates when the fish pass through hydroelectric turbines, spillways, or bypass systems of dams. Such studies have been common on the dams of the Columbia River system, and there are many other applications for this theory for marked animal experiments. Accompanying the monograph is a computer program for the PC class of computers; this program aids in the design and analysis of these survival experiments.

The striped bass population of the Savannah River in Georgia and South Carolina is primarily riverine and spawns in the tidal estuary about 12–25 miles from the Atlantic Ocean. The estuarine spawning area historically was primarily fresh water during the striped bass spawning season, and currents necessary to buoy the semiplanktonic

eggs were provided by river and tidal flows. Maintenance of appropriate current velocities and water quality during incubation is essential for successful reproduction. Researchers at the Georgia Cooperative Fish and Wildlife Research Unit are concerned about the influences of navigational and industrial development in the Savannah Harbor on striped bass spawning. Their concern intensified in the late 1970's, when a tide gate and diversion canal were installed in the estuary to reduce sedimentation in the shipping channels of the harbor. Studies in 1984-89 of long-range influences of harbor development on spawning included monitoring annual egg production, estimating influences of salinity on egg survival, and determining pathways and rates of egg transport in the estuary and harbor. Other study results showed that numbers of striped bass that were spawned in the estuary declined by about 95% between 1978 and 1989. The reduction of spawning probably reflected decreased abundance of adults from previous unsuccessful recruitment. Principal influences of the tide gate on the estuary include increased salinity in the spawning grounds and alteration of current velocities and pathways of water movement in the middle and lower estuary, which in turn accelerate transport of eggs and larvae to areas with salinities that often exceed tolerance limits. The findings will be used to develop recommendations for changing operation of the tide gate and further regulation of harbor development.

The Georgia unit also evaluated behavior of adult striped bass in the Flint River-Lake Seminole portion of the Apalachicola River system to

determine if temperature preferences differed from those of striped bass from Atlantic stocks. Radiotelemetry techniques were used to monitor fish distribution and temperature selection from March 1984 to November 1985. The fish ranged widely and occurred throughout the 103-mile study area during fall, winter, and spring. During summer, however, they inhabited cooler spring-fed areas almost exclusively. When the data were separated into subsets of native Gulf and introduced Atlantic striped bass, there were no differences between groups for average temperatures selected during summer or for temperatures at which the fish moved into or out of springs.

The Maine Cooperative Fish and Wildlife Research Unit recently completed several years of research on the effects of stocking sea-run Atlantic salmon in native brook trout streams. The studies demonstrated that brook trout growth and density may not be affected by the presence of salmon because trout select different habitat when competing with juvenile salmon.

Biologists at the Massachusetts Cooperative Fish and Wildlife Research Unit are studying American shad, blueback herring, Atlantic sturgeon, and the endangered shortnose sturgeon to reduce human disturbance of fish movements in major rivers. The study examines migration routes and the vertical distribution of fish in the water column. With radiotelemetry, biologists are determining the effects of light intensity on habitat selection and daily movement. Other information from these studies, including reproductive ecology, population size, and habitat selection, will help managers protect this endangered species and mitigate for associated anadromous

species. Biologists at the Massachusetts unit also monitored spring migrations at two fish ladders on hydroelectric dams in the Connecticut River to estimate the number of shad returning to spawn.

Atlantic salmon captured at a hydroelectric facility on the Connecticut River were used as brood stock for the Connecticut River Atlantic Salmon Restoration Program. Unit biologists coordinated the release of 125,000 Atlantic salmon fry in 1989 and 300,000 in 1990 into tributaries of the river. They are now studying the growth, survival, and microhabitats of salmon juveniles in relation to habitat availability and resident fish community structure. This information will help managers refine stocking guidelines for the program.

Washington Cooperative Fish and Wildlife Research Unit personnel have been studying gravel scalping—removal of alluvial material above the waterline for flood control—to determine its effects on rearing habitat for juvenile coho salmon and steelhead trout. Preliminary studies in channelized rivers in west-central Washington and in three rivers in the Puyallup River drainage in western Washington indicate gravel scalping eliminates highly used pool habitat in side channels at the downriver end of scalped gravel bars. Elimination of this habitat may induce sublethal effects on these fishes through forced relocation to unsuitable habitat. Because side-channel nursery habitat is infrequent in channelized rivers, gravel scalping may further diminish the rearing potential of these rivers for juvenile coho salmon and steelhead.

Aerial view of a treatment site on the Puyallup River before and after gravel scalping. A highly used side channel pool (SCP) habitat at the downriver end of the gravel bar to be scalped was eliminated and replaced by main channel riffle (MCR) habitat (*Line* in lower drawing indicates the location of the gravel bar before scalping; *arrow* indicates direction of flow).

Before scalping

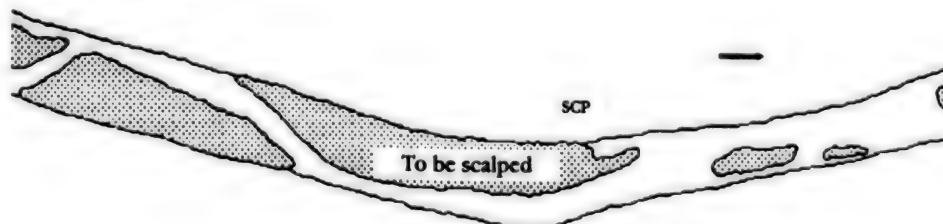


After scalping

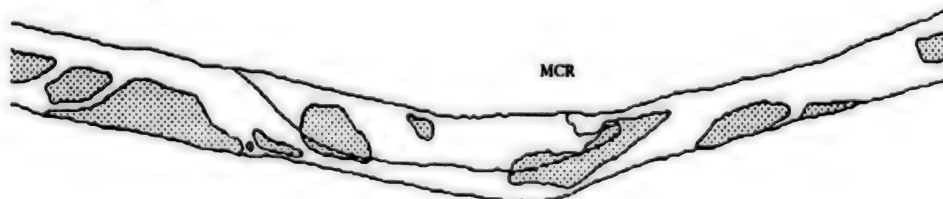


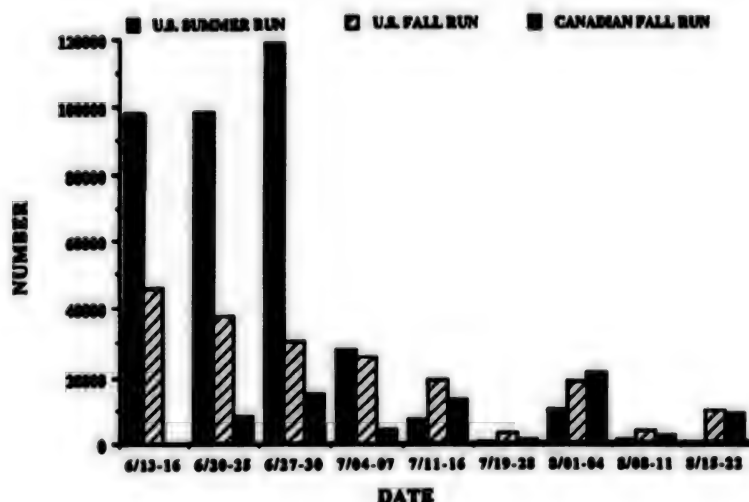
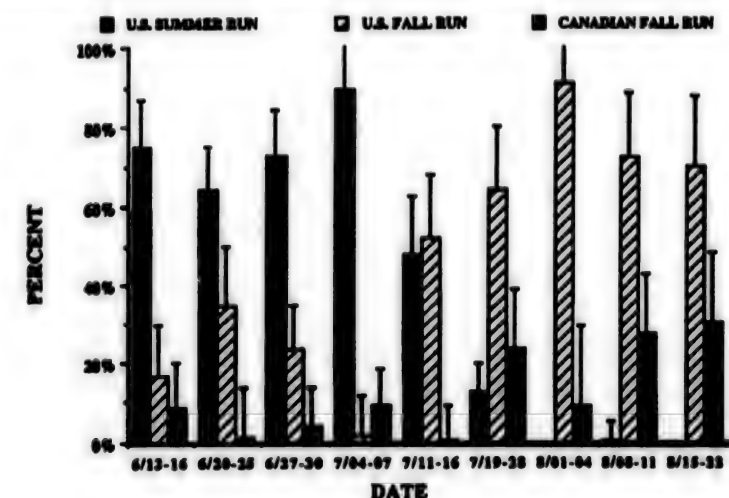
Aerial view of a treatment site on the Carbon River before and after gravel scalping. A highly used side channel pool (SCP) habitat at the downriver end of the gravel bar to be scalped was eliminated and replaced by a main channel riffle (MCR) habitat (*outline* in lower drawing indicates the location of the gravel bar before scalping; *arrow* indicates direction of flow).

Before scalping



After scalping





Genetic Stock Determination Studies

Chum and chinook salmon harvested by the United States in the lower Yukon River in Alaska spawn in both the United States and Canada. Both nations are negotiating a treaty to properly allocate the stocks harvested in the U.S. fishery. Because little is known about the specific areas of origin of salmon and their migrational timing in the mixed-stock fishery, the Alaska Fish and Wildlife Research Center, in cooperation with the Service's Fisheries Management Division, the Alaska Department of Fish and

Game, and biologists in Canada, began genetic studies to determine the percentage of salmon contributed to the Yukon River fishery by stocks in each country. Information from 1987 chum salmon samples indicates that summer-run stocks of U.S. origin, not previously factored in Canadian analyses, are a large proportion of the catch. Stocks originating in rivers near the U.S.-Canadian border are difficult to distinguish and may require use of additional genetic and other characteristics for accurate identification.

Seattle researchers began a study to evaluate life history adaptations of anadromous salmonids in western North America. A model based on

classical population genetics theory was constructed to address the question of depressed performance by certain hybrid chinook salmon stocks. These researchers found that at first very similar parental stocks might give rise to young with hybrid vigor but the hybrid advantage tends to decline rapidly as parental stocks change and become more like one another through cross-breeding.

Seattle researchers also used spawner-recruit relations to suggest sustainable harvest rates in the upper Columbia River for both wild and supplemented populations of spring chinook salmon. Sustainable

harvest rates probably average 25–35% for wild populations. Rates for supplemented populations were slightly higher, the sustainable catch was greater, and both depended on the number of recruits per spawner for fish that were released from hatcheries. To avoid endangering individual populations of fish, scientists determined that minimum goals for loss through escapement should be established for each population, and that sustainable harvest rates should be implemented only if enough fish are present to afford minimum escapement.

Researchers at the National Fish Health Research Laboratory—Lee-town used an enzyme-linked immunosorbant assay to detect antigenic differences in serum albumins of striped bass from geographically isolated spawning populations. Results showed that 92% of the northern (Canadian and Hudson rivers) and 95% of the southern (Chesapeake Bay and Roanoke River) fish were correctly classified. This assay will be used to estimate the composition of coastal migratory stocks and, concomitantly, the effect of

fishing on the Chesapeake Bay and Hudson River productions.

In conjunction with Lifecodes Corporation, Leetown researchers also identified several DNA hybridization probes that will be useful for DNA fingerprinting of striped bass. These fingerprinting techniques will be used to identify progeny of specific matings, thus allowing non-invasive marking of fish.

The California Cooperative Fishery Research Unit completed an analysis of genetic variation in steelhead trout populations of the South Fork Trinity River in northern California. A restoration plan was subsequently developed that includes restocking of underutilized streams.

Population Ecology and Management

Six Atlantic salmon stocks were reared concurrently at the National Fishery Research and Development Laboratory—Wellsboro from hatch through the 1-year smolt stage. Landlocked stocks grew significantly faster than any of the four Penobscot River stocks. Correlation between fi-

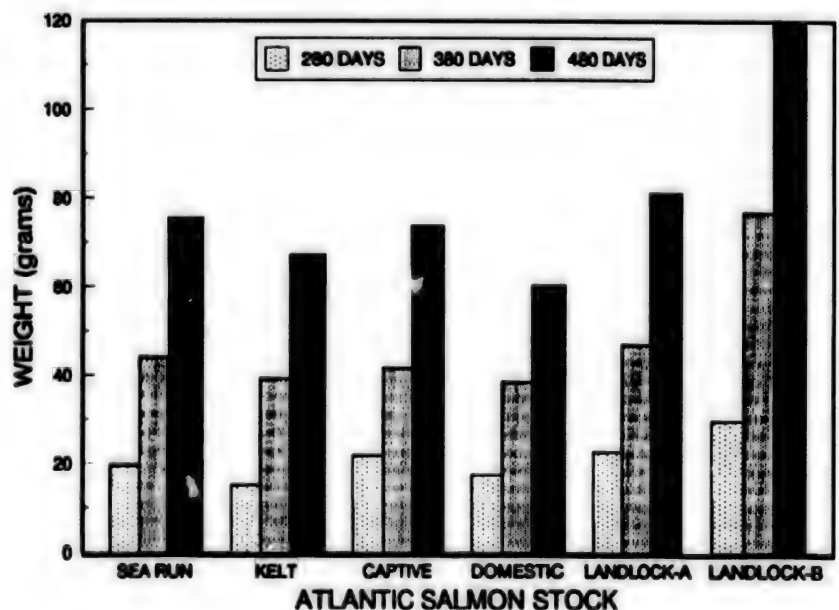
nal weight and the number of generations removed from the wild was inverse, and landlocked stocks had significantly more abnormalities than nonlandlocked stocks.

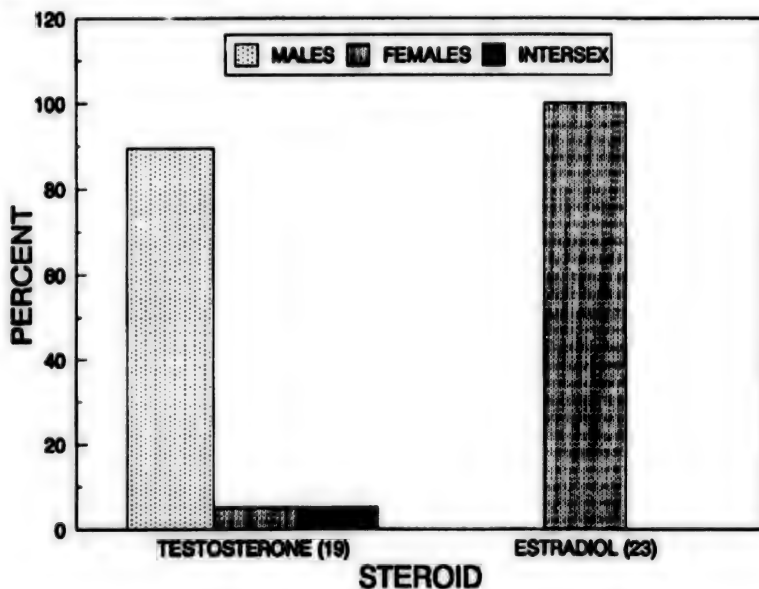
Other work at Wellsboro showed that chemical sex reversal is an effective technique for producing all-female populations of Atlantic salmon. Managers now can significantly increase the number of females in sea-run populations and thereby nearly double reproductive potential of hatchery-research in a single production cycle.

Physiological and genetic comparison of Delaware and Columbia River shad, also at Wellsboro, demonstrated distinct differences. American shad from the Columbia River were more tolerant to salinity and temperature changes than conspecifics from the Delaware River.

An Atlantic salmon brood stock management and breeding handbook was edited by researchers at the National Fisheries Research Center—Great Lakes. They compiled data on breeding systems designed to minimize the frequency of matings between close relatives, as well as other important genetic management considerations.

Comparison of attained weight of six Atlantic salmon stocks at age 3 when reared concurrently at the National Fishery Research and Development Laboratory.





Sex ratios in 16-month old Atlantic salmon treated with methyltestosterone and estradiol. All-female progeny in a stocked year class nearly double reproductive potential of hatchery-reared fish.

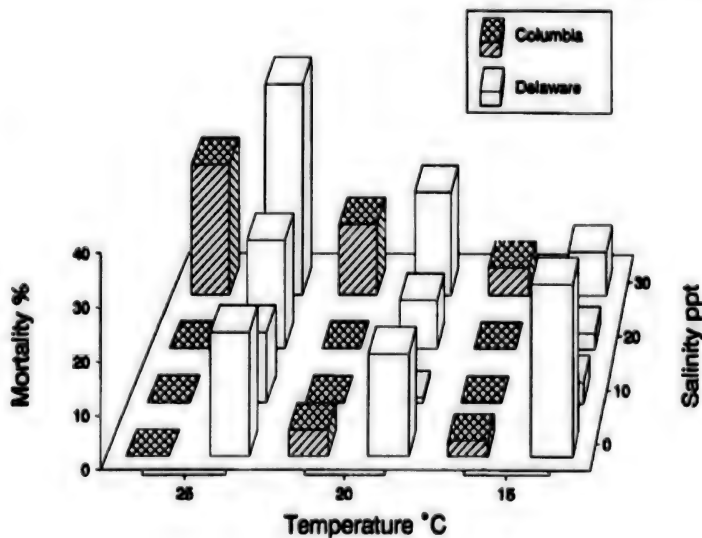
The National Ecology Research Center—Fort Collins is enlarging and enhancing the fisheries management role of the Instream Flow Incremental Methodology (IFIM). Water management decisions will be based on the development of species-specific population life tables and standing crop estimates in a riverine environment limited by levels of suitable physical microhabitat and macrohabitat. The ongoing testing and model development for use by

Service field offices will couple population modeling concepts with reservoir operations, including hydropower production facilities, hydrology, temperature, and habitat.

At the request of the U.S. Army Corps of Engineers, researchers at Seattle addressed the question of whether riprap in the Sacramento River, California, reduces production of chinook salmon. The study

involved reviewing existing data, primarily from the Sacramento River, and developing a conceptual framework for addressing the question. Researchers concluded that, because growth rate responds to population density and can be accurately measured, it may be suitable for use as an index in projects designed to detect density effects. Variable and extensive movement of juvenile salmon within the river and problems with estimating den-

Mortality in two stocks of American shad exposed to different temperatures and salinities for 14 days.



sities of young salmon at different stages in their life cycle prevented development of satisfactory strategies for assessing density-related effects on mortality. Effects of riprap on production of adult salmon are unknown and probably will remain so because the problem is complex and future management actions and habitat conditions are uncertain.

A new method (Interaction Assessment) developed by the Seattle staff uses a modified IFIM to generate mathematical expressions for mortality rates of stream fish as a function of microhabitat. The generated equations can be used to assess relative survival value of substrate, cover, competition, predation, population density, and physical factors such as temperature and flow. This tool has potential for multispecies management and as a guide to stream habitat improvement.

In a joint study with the Oregon Department of Fish and Wildlife (ODF&W), Seattle center researchers documented significant predation by resident fish on out-migrating smolts in the John Day Reservoir on

the Columbia River. Losses to predation were significant in the reservoir, but not known is the significance of predation in mortality in other Columbia River reservoirs and whether predators selectively feed on stressed, diseased, or injured smolts rather than healthy smolts. During the past 2 years, center biologists have (1) determined the maximum daily consumption of juvenile salmonids by northern squawfish, the major predator in the Columbia River system, (2) developed a technique to estimate and compare the relative magnitude of juvenile salmonid consumption by northern squawfish in reservoirs throughout the basin, and (3) developed laboratory techniques to determine if predators select stressed or physically injured juvenile salmonids as opposed to healthy smolts.

Also in cooperation with the ODF&W, Washington Department of Fisheries, and National Marine Fisheries Service, Seattle researchers are helping determine the population status and habitat requirements

of white sturgeon in the Columbia River downstream from McNary Dam. The center's responsibility is to describe reproductive and early life history characteristics of white sturgeons and to define and quantify habitat requirements for spawning and rearing. To date, researchers have discovered white sturgeon spawning grounds below each of the four downstream dams, observed their spawning activity and behavior, and witnessed spawn predation by several species. Additional results indicated poor reproductive success in the lower three pools since 1986 because of low flow, which in some instances delayed spawning until water temperature exceeded levels reported to be lethal to the eggs.

Culture Techniques

During stock-out pond experiments, 1-year-old Atlantic salmon reared at the Wellsboro laboratory

Residue depletion studies on Atlantic salmon are required by the Food and Drug Administration for the registration of antibacterial drugs used in fish culture.
Photo by L. L. Marking.



appeared to be in better condition and behaved more like smolts than 2-year-old fish, but neither smoltified before leaving the ponds. However, stock-out ponds do allow stocking sufficiently early in the season to avoid handling during smoltification when the fish are sensitive to stress and scales are easily lost.

Fin quality is one criterion a hatchery manager uses to assess fish health and appropriate tank density. Researchers at Wellsboro also successfully reared Atlantic salmon at up to 4.3 pounds per cubic foot of water (higher than in production hatcheries) without reducing fin quality. These results suggest that Atlantic salmon rearing units can be smaller than usual for production hatcheries or that fish numbers can be increased if water quality is not compromised.

Seattle researchers, in cooperation with the University of Washington and the International Pacific Halibut Commission, continued studies on spawning and rearing the young of Pacific halibut. During the 1988–89 winter spawning season, sac-fry were successfully raised to 20+ days posthatch. Based on those results, new techniques have

been developed to increase survivability, but environmental conditions (i.e., warmer-than-normal ocean temperatures) during the 1989–90 season kept the females from properly maturing; therefore, no spawning occurred. Canadian researchers on Vancouver Island experienced similar difficulties. Work in 1990–91 will focus on spawning, rearing, and holding adult brood stocks in net pens.

Great Lakes Fishes

Tribal Treaty Fishing

"Made and concluded at the City of Washington in the District of Columbia, between Henry K. Schoolcraft, commissioner on the part of the United States, and the Ottawa and Chippewa nations of the Indians, by their chiefs and delegates" read the Proclamation of the Articles of A Treaty of 1836. These words became the first step in continual efforts to resolve longstanding problems with the allocation of fishery resources in

the Great Lakes. Joint trusteeships have been created among the tribal and State natural resource management agencies. The Service also shares this trusteeship because of its leadership and commitment to rehabilitation of the Great Lakes fisheries and because of the Department of the Interior's responsibilities to tribal Native Americans.

Biologists of the National Fisheries Research Center—Great Lakes, specializing in fish population dynamics interpret collected information on all the lakes and provide technical advice to interagency working groups. These groups establish annual Total Allowable Catch quotas for lake trout, lake whitefish, and bloaters in northern Lakes Huron and Michigan and in Michigan and Wisconsin waters of Lake Superior.

Service fishery biologists also provide technical leadership and information from studies for reports required by the 1985 Entry of Consent Order Agreement and a subsequent Federal court order upholding settlement of a long treaty-rights dispute. The agreement established a technical fisheries review committee (State, tribal, and Federal biologists)

Signatories to the 1985 Entry of Consent Order. Tribal, State (MI), and Department of the Interior officials were involved in the marathon discussions leading to the agreement. Center biologists provided biological support to this vitally important decision-making event.

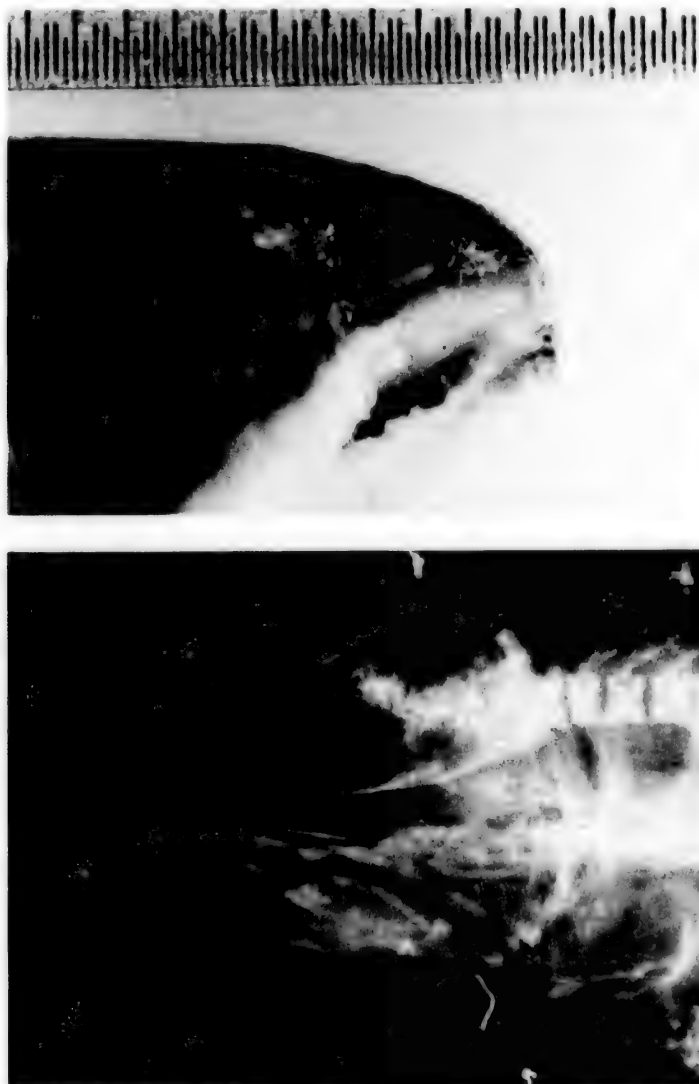


to annually assess all fish stocks in the 1836 ceded waters, as well as in four informally recognized lake trout refuges and rehabilitation zones in the upper Great Lakes. Studies of catches by tribal fishers revealed that catches of lake trout have been maintained at around 600,000 pounds, lake whitefish catch rose from 2.6 million pounds in 1984 to over 5 million pounds in 1988 (out of a total catch of 7.5 million pounds), bloaters catch increased from 270,000 pounds to over 400,000 pounds, and salmon catch rose from about 0 to over 500,000 pounds. Data suggest that the forage base is presently unstable,

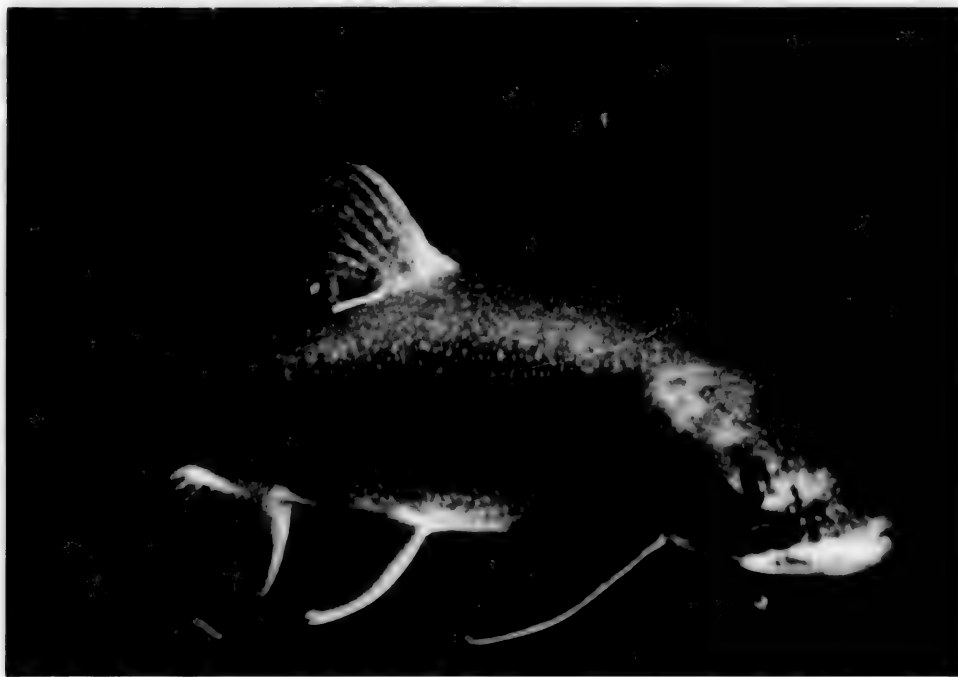
shifting from alewife-dominant to bloaters-dominant populations in Lakes Michigan and Huron, and from smelt to herring in Lake Superior.

The new 1854 Treaty Authority was created by a recent agreement between the State of Minnesota and two Chippewa bands in Minnesota. The two tribal groups requested participation by center personnel on an interagency task force to develop integrated fishery management projects within the 5-million-acre ceded territory. For Lake Superior, the task force developed proposals for study-

ing the distribution and abundance of potentially commercial fish stocks, lake trout stock size and total allowable catch, stock data on other commercial species, the genetic diversity of the ruffe, and the abundance of spawning sea lampreys. Center scientists also serve on technical committees for estimating total allowable catches of lake trout on a management unit basis for 1842 Treaty waters in Michigan and Wisconsin. Center participation will help promote harmonious use of the fishery resources of the Great Lakes.



These lake trout were tagged with small (2 mm) stainless steel coded wire tags. The upper photo shows the location of the tag in the snout of a yearling fish immediately after tag placement (photo courtesy of Northwest Marine Technology, Inc.). The radiograph shows the tag in the head of a 6-year-old lake trout from Lake Ontario. Note the location of the tag (large arrow) behind the orbit of the eye (small arrows)—just one of places that tags can be recovered, presumably as a result of original tag placement or migration. Information from this study will help fishery researchers improve tagging and recovery techniques, which lead to improved management strategies. *Photo by R. Potter.*



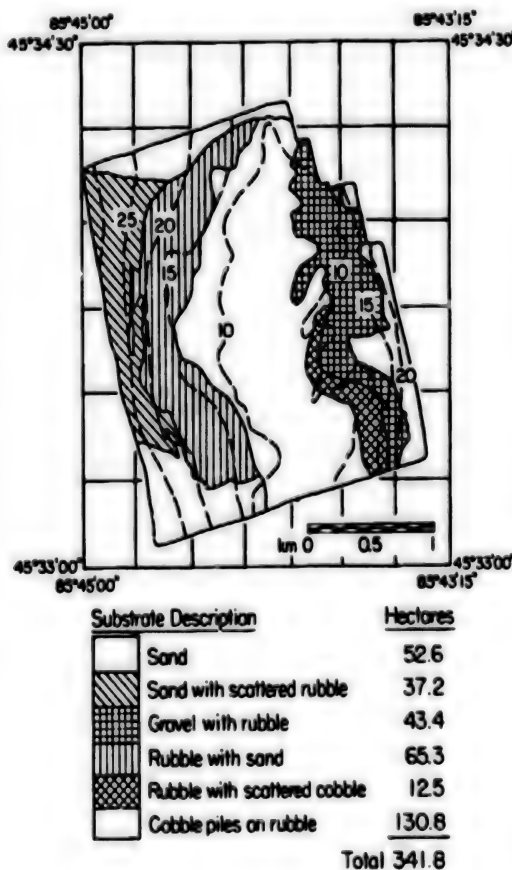
A male lake trout displays its dark nuptial stripe while swimming near the surface of Gull Island Shoal, a spawning ground used by native lake trout. This fish had been recently captured and Floy-tagged by the Wisconsin Department of Natural Resources as part of a long-term reproduction study. The fish was photographed at night in October 1988 in the open waters of western Lake Superior near the Apostle Islands. *Photo by G. Kennedy.*

Lake Trout Restoration

Strain Evaluation

Suitability of the hatchery-reared genetic strains lake trout has been a concern since stocking efforts were started in the 1960's. About 1.5 million lake trout were marked with coded wire tags and stocked to identify strains best suited to conditions in Lake Huron. Three strains (Lake Superior-Marquette, Jenny Lake-Lewis Lake, and Seneca Lake strains) were stocked in appropriate habitat near shore and on midlake reefs. Poststocking survival, growth, and distribution were monitored. Tag recovery from 300 lake trout revealed that the fish strayed an average 47 miles from the stocking site, whereas others (about 25% of age 3 and 4 fish) remained within 6 miles of the midlake reef-stocking site. The Jenny Lake-Lewis Lake strain dispersed faster than the other two strains.

For further evaluation of differences in the three strains, the center examined changes in seven



Side-scan sonar, a remotely operated underwater vehicle, a four-person mini-submarine, and a computer-linked Geographic Information System were used to produce substrate and bathymetric maps of 10 historical lake trout spawning grounds throughout the five Great Lakes. Fishery managers are using the maps to pinpoint locations where lake trout can be stocked with the assurance that returning adult fish will encounter suitable habitat for spawning and fry production.



Technicians conduct annual cataract evaluations of yearling lake trout at the Allegheny National Fish Hatchery stocking in Lake Ontario and Lake Erie. *Photo by H. Kincaid.*

plasma hormones during reproductive maturation in lake trout held under controlled laboratory conditions. Investigators found no pronounced differences between strains in hormonal cycles or gamete ripening times. Distinct patterns in the cycles of individual hormones coincided with ovulation in females and spermiation in males, and were similar to reported patterns in other salmonid species.

Allozyme analysis also was used to compare five strains of lake trout stocked in Lake Ontario for a joint study by the National Fishery Research and Development Laboratory—Wellsboro and Cornell University. Eighteen of 102 gene loci were polymorphic, indicating that more work with electrophoretic methods may help identify stock origin of young lake trout in Lake Ontario.

Biologists from the Wellsboro laboratory and the Allegheny National Fish Hatchery also found significant differences in frequencies of nuclear cataracts in the eye lenses of Superior, Seneca, and Ontario stocks of yearling lake trout. Cataracts occurred more frequently in Lake Superior fish than in Lake Ontario fish. In the hatchery, nuclear

cataracts persisted and increased in frequency in contiguous downstream sections of a raceway. Most cataracts appeared in fingerlings and seemed to be stress-related.

Predation

Studies of predator-prey interactions in the northern Lake Michigan lake trout refuge revealed that burbot of all sizes (12–31 inches) consumed small crayfish, which are abundant on the reefs, but only 16-inch and larger burbot preyed on stocked yearling lake trout. Larger burbot (19–28 inches) preyed most intensively on the lake trout and were 28% more abundant in May and June, when the trout were stocked, than in July and August. These data suggest that stocking strategies to minimize losses should be considered.

In other laboratory studies of predation, we found that crayfishes and sculpins each ate 1–2 eggs or sac fry per day. At typical crayfish and sculpin densities (more than one per square yard) over the usually 120-day lake trout incubation period, crayfishes or sculpins eating

one to two eggs daily could eliminate lake trout eggs at low spawning densities. Thus, peak populations of small predators would significantly reduce lake trout survival over long time intervals.

Spawning Habitat

Mortality of fertilized lake trout eggs on spawning reefs in Lakes Huron, Michigan, Ontario, and Superior is a major concern. Scientists from the National Fisheries Center—Great Lakes placed trout eggs in Plexiglas cages and buried them among rocks on the spawning reefs. The hatch of eggs from the reefs was consistently lower than the hatch of control eggs in the laboratory, indicating that environmental factors in each lake kill lake trout eggs. In laboratory studies scientists found that fry from Lakes Michigan, Huron, and Superior fed and grew much better than fry from Lake Ontario. Ontario fry also failed to fill their swim bladders, did not feed, lost equilibrium, and died of starvation. These behaviors had previously been noted in lake trout fry from areas of Lake Michigan that are heavily contaminated with PCB's.



The parasitic copepod *Salmonicola corpulentus* was first noticed on bloaters collected in U.S. waters of Lake Huron in 1985. Parasites can be used as biological tags to identify groups or stocks of fish. This technique could provide fishery managers with a simple biological means of identifying stocks of valuable whitefish resources in the Great Lakes. Photo by C. Bowen.

None of the fry from Lakes Superior or Huron exhibited this behavior. In the surviving fry, blue sac disease and body deformities, such as spinal curvature and asymmetry, occurred more frequently among individuals from western Lake Ontario (12%)

and eastern Lake Ontario (2.6%) than among individuals from Lake Huron (1.4%), Lake Michigan (1.4%), or Lake Superior (0.4%).

Together with other known sources of mortality such as predation, effects from contamination partly explain why rehabilitation of self-sustaining stocks of lake trout has

been slower in the lower Great Lakes than in Lake Superior.

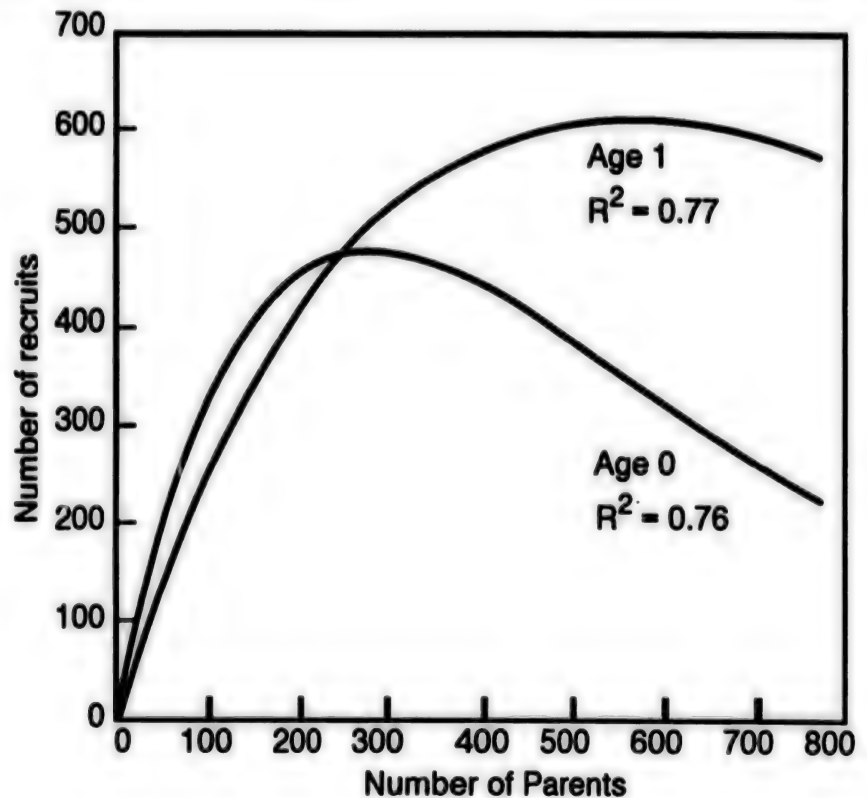
Progress—The Good News

Age 4 fish stocked from the Wyoming strain of lake trout (descended from Lake Michigan fish planted in Yellowstone Park in the late 1800's) were more numerous

A courting male (*lower right*, with dark stripe on side) escorts a female (*upper fish*) at night along the surface of Tawas Reef, an artificial reef where planted lake trout spawn in western Lake Huron. This and other behavior studies will improve management strategies for the restoration of lake trout. Photographed from videotape made in October 1989 with remotely operated vehicle. Photo by G. Kennedy.



Density-dependent recruitment in Lake Michigan bloaters in 1973–88, shown by Ricker curves fitted to catch per trawl tow. The steeper right hand slope of the age-0 recruits appears to reflect lower catchability resulting from slower growth in addition to reflecting lower survival.



in the northern refuge of Lake Michigan than two Lake Superior strains, based on straying, relative survival, and growth. Percentages of lake trout wounded by sea lampreys in Lake Michigan remained very low. The only increase recorded was for the largest fish in southeastern portions of the lake.

Although trout reproduction occurs in several areas of the Great Lakes, only Lake Superior has a sufficiently large population of wild trout to study rehabilitation. On Gull Island Shoal, a spawning reef in western Lake Superior, young wild lake trout of relatively small size leave their natal reef primarily with prevailing currents. By midsummer, they are found more than 5 miles away. As water temperature declines and the frequency of fall storms increases, the fish descend into progressively deeper water. Correlations of long-term data suggest that the abundance

of wild females is the most accurate predictor of the strength of the succeeding year class. Accordingly, as spawning stocks are established elsewhere in the Great Lakes, special protection should be afforded the adults to assure naturally reproducing populations.

Whitefish: The Cash Crop

Coregonines, or whitefish, have been the most important commercial species of fish in the Great Lakes and are a vital source of food for lake trout and, to a lesser extent, salmon in the Great Lakes. In the past, excessive fishing, habitat degradation, and competition and predation by introduced species have all contributed to a reduction in densities of benthic and deepwater coregonines, thus, these factors are being intensively investigated. Morphological evidence also suggests that introgres-

sive hybridization (mixing of gene pools) may have further reduced some populations. Interspecific competition under known feeding conditions was demonstrated between juvenile lake herring and bloaters in a small lake. Within 2 to 3 weeks after hatching their zooplankton diets overlapped considerably. At 6–8 weeks of age the diets were virtually the same. Other contributing factors, such as depth and timing of hatch, are also under study. Successful management of whitefishes depends on comprehensive scientific assessment information. Today only 4 of the 11 postglacial species make up the predominantly benthic and deepwater communities. The stability of these species is uncertain, but their exceptional resilience is an advantage in a vitally important fishery.

Walleye: The "Lake-Erie-Is-Alive" Fish

There was a profound recovery of walleye populations in Lake Erie between 1976 and 1986. Stocks increased not only in the western basin, but also in the central basin where walleyes had been nearly absent for decades. However, relative abundance indices of young-of-the-year walleyes declined during the past three years. Catch data indicated poor reproduction in 1987 and a further decline in 1988. Walleye reproduction continued to decline in 1989, when the young-of-the-year abundance index plummeted to pre-rehabilitation levels. After three successive years of poor recruitment, walleye harvest increasingly depends on the strong 1986 year class.

Forage Fishes

Lake Superior

The native lake herring and the exotic rainbow smelt are the major forage species in Lake Superior. They have experienced profound

population changes in the past several decades.

Historically, lake herring in Lake Superior yielded larger commercial harvests than all other species combined and were the major food of native lake trout. Recent increases in herring biomass are attributable to the production of moderate-to-strong year classes in several years in 1978-88, especially in 1984 and 1988. Their strongest herring recovery is occurring in Wisconsin waters west of the Apostle Islands and in the Keweenaw Bay and Munising areas of Michigan waters.

Rainbow smelt entered Lake Superior in the early 1930's and reached commercially harvestable levels by 1952. By 1981, smelt populations were dominated by 1- and 2-year-old fish and the spawning stocks consisted of 3-year-old fish. As the age composition was degraded, the size composition of the stocks also deteriorated, and by 1989, no smelts larger than 8 inches were taken from U.S. waters. The decline in smelt biomass is the result of excessively high mortality, the cause of which remains unknown.

Lake Michigan

Information about the recovery of the bloater in Lake Michigan in the 1980's provides an excellent opportunity to validate classic recruitment patterns in this important native species. Bloaters again dominate the prey-fish community in Lake Michigan and support significant commercial fisheries. The previously dominant alewives had depressed bloater recruitment by preying on their larvae and by depleting the zooplankton food supply. Data also indicate the recent emergence of density-dependent recruitment of bloaters.

Lake Huron

During fall 1989, researchers observed a substantial increase in bloater abundance, little change in smelts, and a decline among adult alewives over 1988 levels (all data based on fall surveys). Standing stock of Lake Huron forage fish was estimated at 5,300 tons, considerably smaller than the 1988 estimate of 13,700 tons. Catches of young-of-the-year alewives were smaller in 1989 than in 1988, but good condition of (1989 young-of-the-year)

A biologist samples lake herring and bloaters larvae from cages that retain the fish but allow plankton to enter. Competition for limited planktonic resources is suspected as a major factor in the decline of lake herring in Lakes Michigan and Huron, and studies such as this help us understand complex interrelationships among Great Lakes fishes.
Photo by B. Davis.



fish suggested high overwinter survival potential. Adult rainbow smelts increased in abundance in 1989 to a standing stock of 33,000 tons (compared with 25,300 tons in 1988). The standing stock of bloaters was estimated at 61,800 tons in 1989 compared with 32,900 tons the previous year.

Lake Erie

From 1985 through 1987 feeding by the four primary predatory fish species (walleye, yellow perch, white perch, and white bass) on the introduced European zooplankter *Bythotrephes cederstroemi* in the central basin increased in proportion with its rapid expansion in Lake Erie. However, in 1988 and 1989, yellow perch and white perch began to consume fewer *B. cederstroemi* and more of other types of zooplankton, while walleyes consumed clupeids and increased their consumption of yellow perch and white perch.

The Ohio Cooperative Fish and Wildlife Research Unit showed that white perch, a recent invader in Lake Erie, had higher food consumption rates than yellow perch and that both species consumed more and grew faster in the central basin than in the western basin of the lake. Diets of the two species were most similar in summer, but less so in spring and fall, when yellow perch predominantly ate benthic organisms and fish while white perch consumed more zooplankton.

Lake Ontario

The alewife is the dominant forage species where it forms the majority of the diet base for salmon and trout. Long-term research on alewife ecology shows mechanisms and magnitude of mortality caused by severe winter weather and influenced by alewife population size and condition. The center has determined how alewife recruitment depends on adult population size. Of the two

other most important forage fishes, rainbow smelt are abundant but small, and populations of the slimy sculpin, an important food of lake trout, are relatively stable. The average size of rainbow smelt declined because intense predation has virtually eliminated smelt longer than 6 inches and because young, planktivorous smelt are growing slowly, most likely because of competition with alewives for limited zooplankton.

The forage base in Lake Ontario is reasonably stable and appears adequate to support existing predator populations. Disruption of the predator-prey system seems inevitable, however, because eventually a severe winter will trigger a catastrophic mortality of alewives. Center biologists are active participants in the formulation of management strategies that consider the cyclic nature of alewife populations.

Habitat Loss or Degradation in the Great Lakes

Loss or degradation of fish habitats in the Great Lakes basin remains a major concern of managers. Studies of confined disposal facilities and water level fluctuations were conducted to identify measures for the protection and enhancement of aquatic habitats.

Fisheries in Confined Disposal Facilities

The 38 units in the Confined Disposal Facilities Program within the Great Lakes region are at various stages of completion. Abnormalities of fish at the Times Beach Facility at the mouth of the Buffalo River in Buffalo, New York, have indicated a presence of contaminants in sediments. This facility was built in 1971 and remains partly unfilled; thus, this facility developed dense populations of submerged vegetation and

aquatic insects. During 1988, the fish community (estimated at 20,000 fish) in an 8-hectare pool of the facility consisted of 18 species. Golden shiner, pumpkinseed, and rock bass were the most abundant species. Although growth of fish in the Confined Disposal Facilities was similar to that of fish in nearby waters, 89% of the brown bullheads had external abnormalities. Accumulation and transport of contaminants may adversely affect the use of habitat created by the Confined Disposal Facility.

Water-level Fluctuations

Water-level fluctuations in the Great Lakes can adversely affect human activities but are required by many natural resources, especially wetlands and shallow aquatic habitats. Center scientists described changes in four wetland plant communities in the upper Great Lakes subject to a 20-inch drop in water level between 1986 and 1988. Most species were found in areas that were flooded in 1986 and dewatered in 1988. Further results indicate that wetland plant communities of the Great Lakes often develop according to topography, and their diversity depends on water-level changes. Only site-specific predictions of wetland response to water-level fluctuations are reliable, and they require knowledge of the species pool, current community characteristics, water-level history, and fairly detailed information on basin morphology.

A study on the effects of historical water-level fluctuations (about 3 feet higher and lower than present levels) revealed that the aquatic ecosystem is generally less affected by water-level change than the adjacent wetlands. Strictly aquatic organisms are able to shift their horizontal and vertical distribution, while extreme low and high fluctuations promote biotic diversity and productivity.

Freshwater and Non-native Fishes

Exotic Species

The National Fisheries Research Center—Gainesville, Florida, has been monitoring the status and distribution of exotic (non-native) fish species from U.S. public waters since 1979. The 126 species of exotic fishes encountered so far include 46 established as breeding populations. The center recently developed a computerized data base for efficient storage and retrieval of nationwide information on exotic fishes and monitoring the distribution and potential expansion of ranges by established populations.

The zebra mussel, an encrusting or fouling organism of sometimes nuisance proportions, is being monitored by the National Fisheries Research Center—Great Lakes. This mussel is common in Europe, and in 1988 was discovered in Lake St. Clair of the Great Lakes. Introduction appears the result of ship ballast discharge of planktonic larvae into Lake St. Clair. Zebra mussels are now common throughout Lake Erie and in western Lake Ontario. They filter great quantities of phytoplankton that are the base of the food web and encrust on valuable native unionid clams, crayfish, and on fish spawning reefs and other essential habitat of native species. Zebra mussels also clog water intakes, foul commercial fishing nets and boat hulls, infest swimming beaches, cause change in feeding and migration patterns of mussel-eating waterfowl, and cause change in the feeding behavior of some fishes.

The rudd, native to Europe and central Asia, is established in Maine and New York. Originally imported as an ornamental fish, it is also used as bait. Rudd have been observed in public waters of Arkansas, Kansas, Illinois, Missouri, Oklahoma, Texas,

Virginia, and Wisconsin. Five States prohibit importation and eight other States are considering or developing such regulations. The rudd hybridizes with the native golden shiner, as demonstrated at the National Fisheries Research Center—Gainesville, and has the potential for competing with and preying on native fish species.

The National Fisheries Research Center—Great Lakes has begun studies on the ruffe, a Eurasian fish that was introduced into Duluth Harbor on the St. Louis River in Lake Superior in 1986. Introduction was probably through discharge of young fish with ballast water from an ocean-going ship. So far there is no evidence of reproduction by ruffe in the Duluth area. Initial attempts at control of ruffe populations in Duluth Harbor were by introduction of predator fish. Preliminary evaluation of these measures indicates that stocked walleye may not be effective in controlling ruffe. However, limited sampling in the estuary showed that some northern pike and burbot had eaten ruffe. The center is assessing potential effectiveness of these two predators in controlling the ruffe population in the harbor.

The Alabama Cooperative Fish and Wildlife Research Unit has been studying the behavior of triploid grass carp and the possible effect of stocking it in Gunter's Reservoir, Tennessee, to control the exotic hydrilla plant. Study results suggest that small grass carp stocked in hydrilla-infested areas feed primarily on this nuisance plant; however, radiotelemetry data indicate that adult grass carp are unlikely to remain in vegetation-control areas.

The blackchin tilapia, an exotic African cichlid, is established on the west coast of Florida near Tampa Bay, Hillsborough and Manatee counties, and on the east coast in the Indian River system, Brevard and Indian River counties. Recent

field surveys by the National Fisheries Research Center—Gainesville in the Indian River demonstrate both northern and southern range extension of this species since its introduction in 1980. Although the northern distribution will be limited by low temperature, there appear to be no barriers to invasion southward along the coast.

Reservoirs and Rivers

The Mississippi Cooperative Fish and Wildlife Research Unit studied distribution, movement, and habitat associations of hybrid striped bass in Ross Barnett Reservoir and observed that upstream migration coincides with increasing water flow, temperature, and photoperiod. Downstream migration related to increasing water temperature, decreasing dissolved oxygen, and lower river discharge. Northern pike in Ohio had higher survival than muskellunge, and both lived longer on the average than tiger muskellunge, according to work by the Ohio Cooperative Fish and Wildlife Research Unit. Survival was highest in the largest fish of each form.

The California Cooperative Fishery Research Unit found that largemouth bass were fully recruited to the fishery at age 3 after initiation of a 12-inch minimum length creel limit for largemouth and smallmouth bass from Shasta Reservoir, as opposed to age 4 recruitment before regulation. There was no change in the age of full recruitment (age 4) for smallmouth bass. Walleye movement in the Tombigbee River indicated upstream spawning from March through early April, according to the Mississippi Cooperative Fish and Wildlife Research Unit. Downstream postspawning movements varied widely. Walleye preferred highly oxygenated water and were associated with standing timber structure during 73% of daytime observations.

Navigation and sedimentation are major issues affecting biotic well being of the nation's large rivers. Collection of fish samples from many different habitats gives a better view of potential effects on riverine fisheries.



Population Dynamics

The Missouri Cooperative Fish and Wildlife Research Unit examined density as a factor in white crappie population dynamics and interactions with bluegill and largemouth bass. Growth of both young-of-year and adult white crappie seemed to be highly density dependent. Adult white crappie, especially at high densities, depressed growth of young

largemouth bass and reproductive success of both largemouth bass and bluegill. The combined young-of-year biomass of the three species was significantly related to mean summer chlorophyll *a* concentration. The Missouri Unit also determined that filling hatching ponds in interrupted stages reduced fertilizer costs for fish production by 36% for largemouth bass and 57% for channel catfish. The

unit further determined that temporal and spatial distribution of age 0 white crappie in Lake Wappapello may be related to recruitment mechanisms, and that large-scale variation in recruitment and heavy summer mortality of young-of-year shad are characteristic of many large reservoirs.

In a two-year study, the Mississippi Cooperative Fish and Wildlife Research Unit determined that feed-



Determining the sample bias tendencies of collecting gear is critical before fishery habitat value can be assessed accurately.



A trawl, designed to be towed alongside an airboat, is used to sample fisheries organisms in shallow marsh ponds in south-central Louisiana.

ing different amounts of trout chow to hybrid striped bass yielded better survival at higher stocking densities (up to 182,000 fry per acre); ponds containing hybrid bass fed artificial feed had greater yields of phase-1 fingerlings. Ponds where bass were fed trout chow from initial stocking exhibited greater hybrid yields than did ponds where bass were not fed until 18 days later. These studies indicated that some 10-day-old fry consumed artificial feed within 3 days after stocking.

Researchers at the National Fisheries Research Center—La Crosse reexamined the Habitat Suitability Index (HSI) model for walleye and, by relating spawning locations to river discharge and stage data, determined that year-class strength was not clearly influenced by water-level changes. However, the poorest walleye production occurred in years when water levels were extremely low.

In another habitat study, the Missouri Cooperative Fish and Wildlife Research Unit determined that most larval fishes were more abundant in the mouths of tributaries than in the adjacent Missouri River. The tributary streams contribute to the diversity of fish species in the Missouri River.

The Environmental Protection Agency examined experimental data provided by the National Fisheries Research Center—La Crosse on chemicals frequently used in fish management and fish culture. The agency concluded that rotenone is nontoxic to humans at treatment levels.

Instream Flow

The Montana Cooperative Fishery Research Unit used radio tagging to examine movements and habitat selection during winter by trout in a stream proposed for small hydropower development. Results

revealed that adult rainbow trout selected high-quality pools with overhead cover, depths greater than 18 inches, and velocities less than 1 foot per second. Trout avoided shallow, swift current without cover.

The National Ecology Research Center completed research on the effects of primary and secondary influences of microhabitat variability on populations of brown and rainbow trout in four Colorado streams. Patterns of significant correlations among habitats—described with Instream Flow Incremental Methodology—and population components of the four streams were explained by habitat structure, hydrologic regime, and fishery management practice.

Personnel of the Pennsylvania Cooperative Fish and Wildlife Research Unit completed a study on an unusual pattern of spatial distribution and densities of brown trout in a central Pennsylvania stream. Densities of trout redds explained about

50% of the variation in trout densities. Densities in the middle third of the stream were low because of a large silt load contributing to the accumulation of fine material in trout redds and to reduced availability of spawning sites.

Effects of delay on the spawning run of Arctic grayling by high water velocities through culverts were studied by the Alaska Cooperative Fishery Research Unit. The study revealed that the maximum delay Arctic grayling can tolerate during spawning migration, without significant reduction in spawning success, should not exceed 3 days. The Montana Cooperative Fishery Research Unit assessed irrigation water withdrawal effects on fry production in two important tributaries of the upper Yellowstone River, and determined minimum instream flows needed to protect all spawning sites in both streams.

Recent work by the Alabama Cooperative Fish and Wildlife Research Unit and the National Ecology Research Center revealed alterations of fish communities resulting from stream flow regulation. Highly fluctuating flow seems to eliminate or reduce the value of shallow, nearshore microhabitats for fishes. In general, streamflow regulation has highly selective effects, depending on fish size and microhabitat use. Studies below hydropower dams also indicate that entirely natural (run-of-the-river) stream flow is not essential in maintaining natural fish communities of streams. Similar studies by other cooperative fish and wildlife units indicate that shallow, nearshore waters are heavily used by diverse small fishes and by juveniles of large fishes. Fish densities tend to be highest in two microhabitats—midstream deep pools populated by large-size fishes, and shallow riffles inhabited by members of small-size fish species adapted to swift currents.

Zooplankton and Ichthyoplankton

Macroplankton drift studies conducted near Port Arthur, Texas by the Louisiana Cooperative Fish and Wildlife Research Unit indicated that larval marine fishes and crustaceans transported through a tidal canal moved vertically and laterally in response to tide and photoperiod. Few individuals of any species were captured during daylight.



A smallmouth bass being marked with a surgically inserted internal anchor tag in a study to identify fishery management options

Drift studies in the lower Mississippi River by the Louisiana Cooperative Fish and Wildlife Research Unit indicate greatest density of macroinvertebrates in April and lowest density in December. Highest densities occurred 4 hours after dusk and lowest at 1 hour before sunrise. Larvae of shad and drum revealed diel abundance peaks related to development stage. Youn-

ger larvae (protolaryae) were highest in numbers during the day and older larvae (metalarvae) concentrated in eddies at night. These results indicate that shoreline concavities should be included in bank stabilization for large rivers.

Similarly, biologists at the National Fisheries Research Center—La Crosse completed two studies that demonstrate shorelines and islands in the main channel can be important production sites for many backwater spawners in the upper Mississippi River. Amount of vegetated surface area, more than type of vegetation, determined abundance of game fish. Although not as productive as backwaters, shorelines and islands can augment production of game fish that are affected by Federal waterway activities.

Predator-Prey Relations

Laboratory and field investigations by the Mississippi Cooperative Fish and Wildlife Research Unit determined over a 2-year period that largemouth bass ate more fish (mainly shads), grew faster, and had lower mortality in a reservoir where shads and sunfishes were about equally available than in a reservoir where sunfishes were the most readily available and most important forage.

Missouri Cooperative Fish and Wildlife Research Unit personnel studied the effect of a 15-inch minimum-length creel limit for largemouth bass on a 205-acre public lake in central Missouri. Growth rates and harvest of both bass and crappie increased. The bluegill population exhibited improved growth rate, population structure, and physical condition.

In a related study, the Missouri unit found that growth and condition of bluegill greater than 2 inches

in total length are affected more by changing density of bluegill than by the presence of gizzard shad. Density (or biomass) of bluegill populations had an inverse relation with growth and condition, regardless of the presence of gizzard shad.

Estuarine Fishes

The National Fisheries Research Center—Gainesville began estuarine studies at Merritt Island National Wildlife Refuge in Florida to determine relative abundance, distributions, movements, and habitat requirements of major game and commercial species, as well as factors that determine year-class strength of spotted seatrout. The study also evaluates refuge canals as nursery areas for red drum fry—a cooperative effort between refuge staff, Florida Department of Natural Resources, and the Gainesville Center.

Endangered Species

Fish and Wildlife Service researchers study endangered species in native habitats to learn more about the ecological factors that have contributed to declines of these species. Researchers also study endangered species in captivity to learn more about the physiology and behavior of the animals and to enhance the species' survival in the wild. This research enables the U.S. Fish and Wildlife Service and other Federal and State agencies to identify and develop management practices that, when implemented, can strengthen recovery of endangered species. The following paragraphs provide short synopses about the Service's research progress on the management and population ecology of endangered species.

Minnesota Gray Wolves

Researchers from the Patuxent Wildlife Research Center's Minnesota Research Group have successfully tested a commercially manufactured capture collar that allows recapture of wolves and other animals on command. The capture collar is a computerized, dart-bearing collar that is controllable by radio signal. Not only does this technique save time, effort, and expense, but it allows studies that used to be impossible. For example, an animal can now be weighed, blood-sampled, and examined once a month. The collar was field-tested more than 80 times on wolves and white-tailed deer under all temperature extremes, and its success rate exceeded 90%.

Researchers have also completed preliminary genetic analyses of mitochondrial DNA in wolves and found that about 60% of Minnesota's wolves show evidence of hybridization between male wolves and female coyotes. At least four such crossings seemingly took place during the past 80 years. However, nuclear DNA shows no evidence of hybridization, suggesting a swamping of the coyote DNA by wolf DNA. This potential for hybridization is a newly discovered threat to the wolf population and is being investigated further.

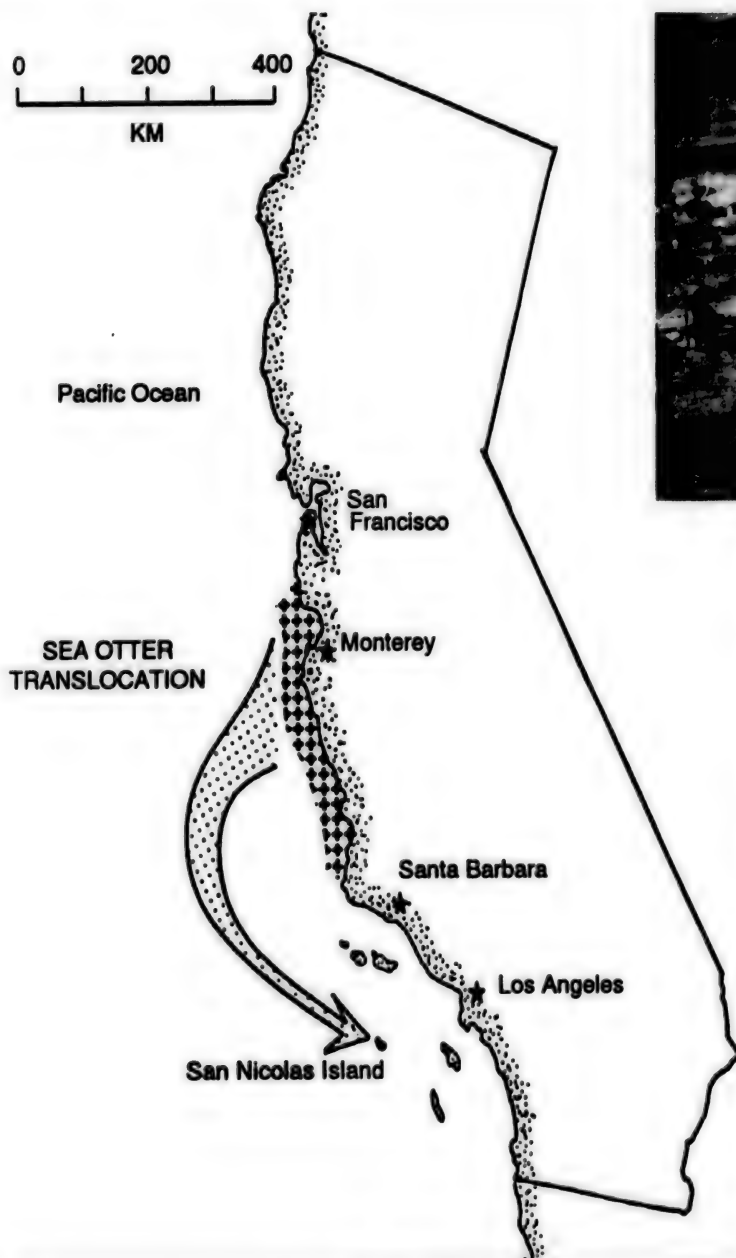
Pacific Fruit Bats

Fruit bats of American Samoa, Western Samoa, and Fiji are threatened by a growing demand for importation of these animals to Guam, where they are a traditional food delicacy. Because of this the Office of Scientific Authority proposed upgrading CITES (Convention on International Trade in Endangered Species) listings for several species of fruit bats. Thus, biologists from the National Ecology Research Center spent the summer of 1989 cen-

suring fruit bat populations on American Samoa, Western Samoa, and Fiji. The Service is particularly concerned about the status of the Samoan fruit bat, of which one subspecies is found only in Fiji. Service biologists and researchers from Bat Conservation International surveyed Viti Levu, the major island in the Fiji group. Their rough assessment of the habitat suggests that the fruit bats should continue to do well on Fiji. In addition, the government of Western Samoa has taken steps to reduce the harvest of fruit bats by restricting the season in which they can be taken.

Sea Otters

By the beginning of the 20th century, uncontrolled fur trade had nearly eliminated sea otters from their entire range in the North Pacific. The population in California has partially recovered but is listed as threatened because of its restricted distribution, small size, and the threat of a catastrophic oil spill. To reduce detrimental effects of a large oil spill on the California population, the U.S. Fish and Wildlife Service is attempting to reestablish sea otters at San Nicolas Island, about 62 miles off the southern California coast and about 155 miles south of the animals' current range. From August 1987 through October 1989, 135 sea otters from the mainland population were released at San Nicolas Island; 13 remained at the end of January 1990. Nearly one-third of the released otters returned to the mainland, the rest are unaccounted for. Although results of the San Nicolas Island translocation are disappointing, establishment of the small colony at San Nicolas Island is still possible, especially if disturbances to the new colony can be reduced and if more sea otters can be translocated to the island.



California sea otter studies. *Clockwise from left:*

Sea otter distribution in California with arrow pointing to translocation site at San Nicolas Island.

Sea otter resting in kelp bed. *Photo by G. Jameson.*

Service biologist capturing a sea otter along central California coast. *Photo by J. Foott.*

Biologists from National Ecology Research Center-Fort Collins radio-tracking and spotting sea otters at San Nicolas Island transplant site. *Photo by J. Foott.*



West Indian Manatees

Seagrass is an important food for manatees year-round and is especially relied upon during cold periods in winter by manatees that gather at warmwater refuges on the east coast of Florida. Thus, the National Ecology Research Center is cooperating with the National Marine Fisheries Service and the Florida Department of Natural Resources in a study of seagrass ecology. Florida seagrass declines have been attributed to adverse effects of high levels of water turbidity that reduce the amount of available light to submerged vegetation. Researchers collected data in Hobe Sound, Florida, on boat traffic, wind speed, and light attenuation to determine effects of boat activity and wind-wave energy on water turbidity. Regulation of boat activity might result in conservation and enhancement of seagrass beds that will benefit manatees and many other aquatic species.

California Condors

During 1988-90, 13 Andean condors, hatched in captivity, were released from 3 sites in and adjacent to the Sespe Condor Sanctuary, an area in the Los Padres National Forest of southern California that used to be inhabited by the California condor. Ten of the 13 birds remain in the wild, two were returned to captivity because of developmental and behavioral problems, and one died. Although the free-ranging birds have moved extensively (up to 99 miles from the release sites), they have remained dependent on food supplied at the release sites. The released condors have remained in habitats formerly used by California condors and have recently begun to roost and nest in sites that were historically used by the native species. These trial releases are encouraging and suggest that captive-born California condors can also be successfully reintroduced into their native range. Because young California condors

may be released into the wild as early as 1991, results from the study with Andean condors are especially timely.

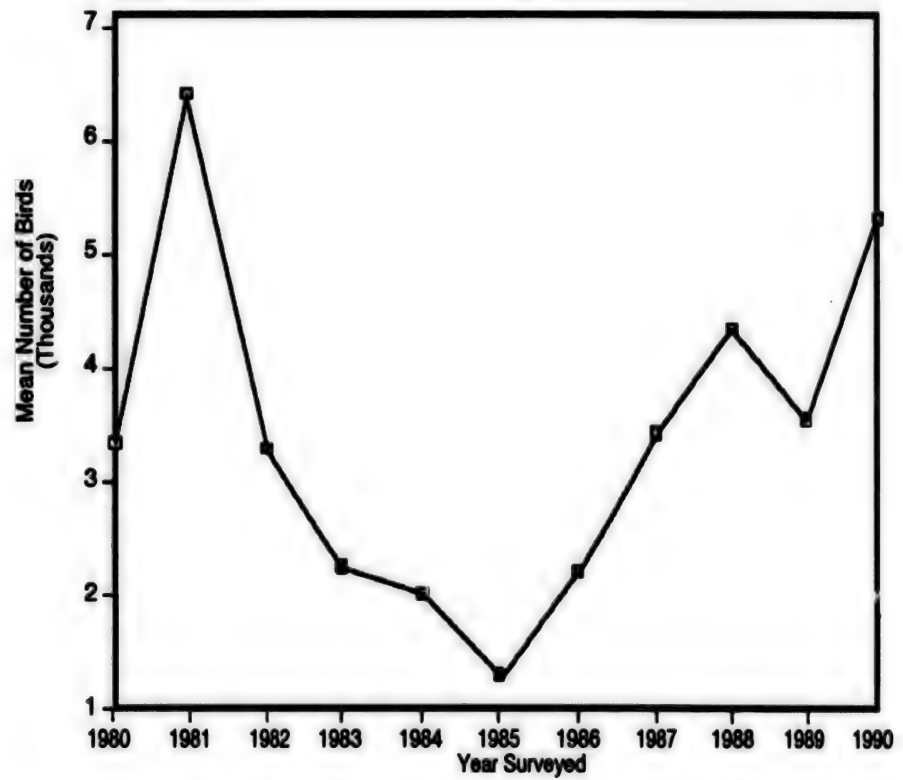
Hawaiian Forest Birds

In 1988 and 1989, scientists of the Patuxent Wildlife Research Center focused on determining factors that limit the distribution and abundance of Hawaiian forest bird species, particularly the palila on the island of Hawaii. Although estimated at less than 1,500 birds in 1985, the palila population has increased over the past several years and was estimated at 5,332 birds in January 1990. Approximately 50% of the known active palila nests in 1989 were successful in fledging at least one bird.



Captive-produced Andean condor chick "R-6," released from the Ridge Site within the Sespe Condor Sanctuary in southern California. Birds carry a numbered wing tag and radio transmitter on each wing to aid researchers in monitoring movements. *Photo by J. Wiley.*

Palila population estimates,
1980-90. Graph by J. Jacobi.



Adult Palila feeding in Mamane
tree.

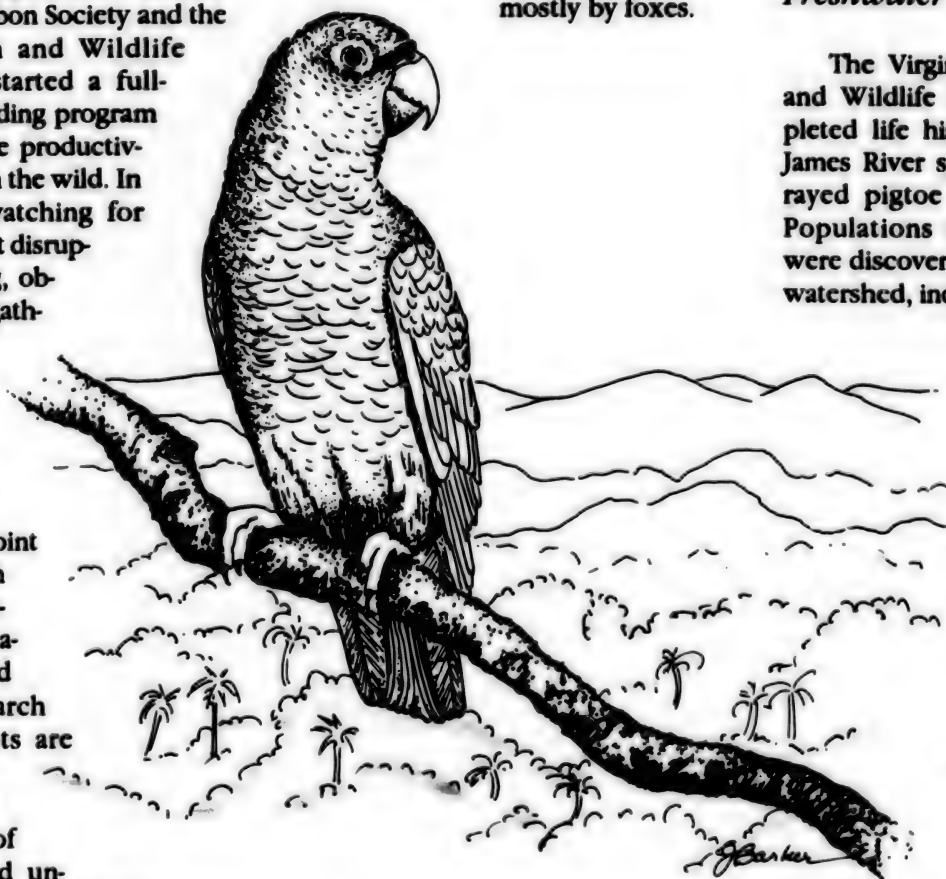
Puerto Rican Parrots

The estimated population of 45–47 wild Puerto Rican parrots in August, 1989, was the largest recorded in recent times. Unfortunately, by September 27, 1989, Hurricane Hugo (September 18, 1989) reduced the flock to about 23 birds. In 1987, the U.S. Fish and Wildlife Service, in cooperation with the National Audubon Society and the National Fish and Wildlife Foundation, started a full-time nest guarding program to enhance the productivity of parrots in the wild. In addition to watching for causes of direct disruption of nesting, observers have gathered data on behavior, nest-site characteristics, and reproductive success. In a joint endeavor with the Massachusetts Cooperative Fish and Wildlife Research Unit, biologists are now analyzing these data for patterns of successful and unsuccessful nesting behavior. The information gained from the data will be important in rebuilding the population.

Piping Plovers

Since the early 1900's, piping plovers have drastically declined because of habitat changes, predation, and increased human recreation on their nesting beaches. The Massachusetts Cooperative Fish and Wildlife Research Unit participated in studies of piping plovers on Cape Cod. Hatching success on Cape Cod

is very low, renesting is frequent, and predation is heavy. To determine the effectiveness of a non-lethal predator-control method, biologists placed circular wire mesh fences around 14 plover nests; 21 nests were not protected. None of the protected nests were destroyed by predators, but 17 of the 21 unprotected nests were lost to predation, mostly by foxes.



Red-Cockaded Woodpeckers

The U.S. Forest Service and the Arkansas Cooperative Fish and Wildlife Research Unit have conducted joint monitoring of the red-cockaded woodpecker colonies in the Ouachita National Forest of Arkansas. A study was initiated to determine clan sizes and composition, home ranges and territories, habitat use, and reproductive success of selected clans. This study is

one of several intended to develop management practices to save this endangered species. As of March 1990, Forest Service and Arkansas Cooperative Unit personnel had live-trapped and color-banded 14 male and 10 female red-cockaded woodpeckers and had identified 12 active colonies.

Freshwater Mussels

The Virginia Cooperative Fish and Wildlife Research Unit completed life history studies on the James River spiny mussel and fine-rayed pigtoe in 1988 and 1989. Populations of the spiny mussel were discovered in the James River watershed, indicating an expansion of the known range.

This species breeds during the summer, uses at least seven species of minnows as hosts for its glochidia (the obligatory motile stage of the mussel), and reaches a maximum age of 19 years.

The fine-rayed pigtoe also breeds in summer, uses at least seven species of minnows and one sculpin as glochidial hosts, and lives as long as 35 years. The best population of fine-rayed pigtoes occurs in the Clinch River, Virginia, but is declining for unknown reasons. A major recovery effort by Federal, State, and private conservation groups is underway to protect the biodiversity of the Clinch River, which has roughly 115 species of fishes and 45 species of freshwater mussels.



Juvenile *Lampsilis* mussels produced in laboratory culture. (A) 1-day-old individual, 0.2 mm in size; and (B) 21-day-old juvenile showing original juvenile body and growth rings, 0.3 mm in size. Photo by B. A. Lasee.

Artificial propagation is necessary for the recovery of many endangered freshwater mussels. Researchers at the National Fisheries Research Center—La Crosse have studied the ecology and culture requirements of the Higgins' eye pearly mussel since 1984. In the laboratory, thousands of newly trans-

formed juveniles can be produced with ease and given immediate access to high-quality habitat. However, rearing of these microscopic juveniles to minimum stockable size (greater than 1/10th of an inch) remains difficult. Although silt and flow requirements in the culture

seem important, nutritional value of cultured food for the young seems to be of even greater importance. Cultured microorganisms and phytoplankton can be used to rear young to stockable sizes, but mortality is variable and high. Commercially available foods are promising. The center has successfully cultured two species, which are related to Higgins' eye, in a combined laboratory and field effort and produced young over 2/10 of an inch in length within 80 days. Where good field conditions can be found, this combined culture technique has the potential to aid in the recovery of endangered mussels.

Desert Tortoises

Biologists from the National Ecology Research Center studied the foraging ecology of desert tortoises near the Beaver Dam Slope, Utah. Researchers attached radio transmitters to 10 desert tortoises and examined food habits and time spent foraging by directly observing the tortoises from mid-April to the end of August 1989. During that time, these tortoises spent only 76 hours foraging but took over 11,700

Nutrition and foraging ecology of the desert tortoise are being studied in the Mojave desert. Photo by T. C. Esque.



bites of 25 species of plants. The introduced annual plants, foxtail brome and filaree, comprised almost 75% of the bites taken by the tortoises.

Red Hills Salamanders

In 1988, researchers from the National Ecology Research Center surveyed 144 sites in the Red Hills Physiographic Province, in south-central Alabama, for burrows of the federally listed (threatened) Red Hills salamander. The salamanders' distinct oval-shaped burrows were most often found on high, steep, uncut slopes with high soil moisture content and full tree canopy. Slope angle and soil pH did not affect burrow abundance. Burrows were most often found on the upper two-thirds of slopes. Red Hills salaman-

ders may survive selective cutting and clear cutting of vegetation in some instances, but the long-term effects of such forestry practices on the salamanders are unknown.

Translocation Strategies

Recovery plans for endangered species often specify translocation of wild or captive-reared animals to reestablish species in the wild, establish additional disjunct populations, or augment existing low-density populations. The Idaho Cooperative Fish and Wildlife Research Unit and the Idaho Department of Fish and Game surveyed recent translocations of native birds and mammals in Australia, Canada, New Zealand, and the United States to estimate success rates and to provide tools for evaluating different translocation strategies. Species recovery through translocation suc-

ceeds only in exceptionally favorable circumstances. Translocating small numbers of animals, captive rearing, poor habitat quality, release areas outside the species' historical ranges, presence of physically similar competitors, and releases over only a few years yielded lowest success. Among animals caught in the wild, translocations were more successful from growing, high-density populations than from low-density and declining populations. Herbivores were translocated more successfully than carnivores or omnivores. Without high habitat quality, translocations of threatened or endangered species had low chances of success regardless of how many organisms were released or how well they were prepared for the release. Releasing more than the optimum number for specific situations does little to increase success.

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Fish and Wildlife Husbandry

Fish Culture and Propagation

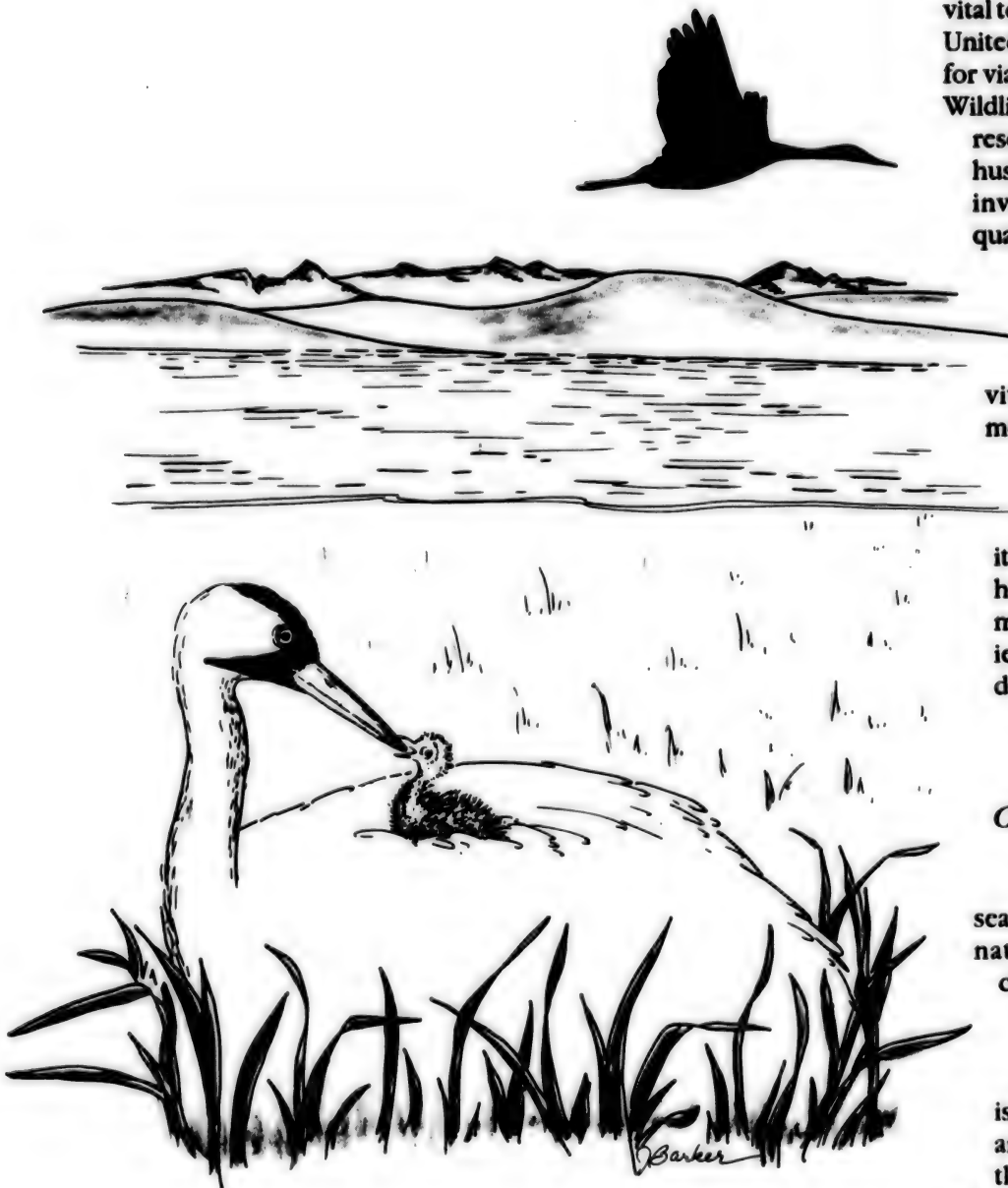
Developing techniques for the culture and propagation of fish is vital to the increasing demand in the United States by fishery managers for viable fish populations. Fish and Wildlife Service scientists conduct research on new and improved husbandry techniques. Scientists investigate and develop high-quality, low-cost fish feed by determining the nutritional requirements of fish.

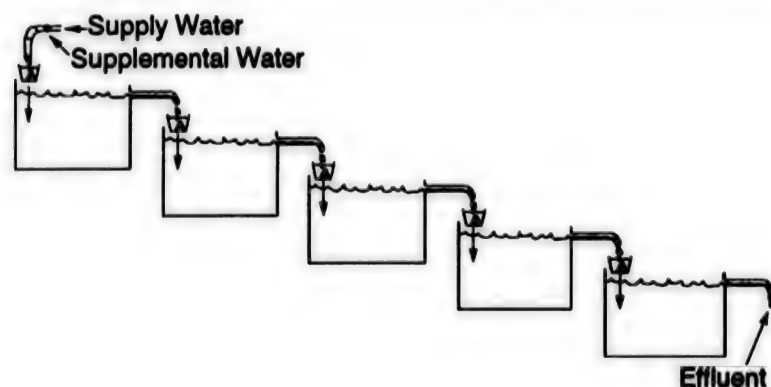
Water quality, critical to the development and survival of fish, is studied, and methods to improve it are developed. Chemical and drug use in fish culture and propagation must be monitored closely. Restoration is enhanced when methods that promote growth of fish in hatcheries and fish size at release are developed.

Chemicals and Drugs

The National Fisheries Research Center—La Crosse, coordinates the Service's efforts in chemical and drug registration.

Recent work by this center resulted in a ruling by the U.S. Food and Drug Administration (FDA) that quaternary ammonium compounds are neither animal drugs nor food additives when used as disinfectants during fish production activities and





In an aerated, serial, water-reuse rearing system, the fish growth rate and prefeeding oxygen consumption rate are determined for each group of fish. *Figure by G. Pardue.*

are therefore not regulated by FDA. Quaternary ammonium compounds can be used as active ingredients for disinfecting water, gear, and tanks used to handle fish and to perform routine operations. The center also gained permission to use tetracyclines to mark young fish. In the wild, marking serves to distinguish between natural and hatchery-stocked populations, aid in life history studies, and estimate population abundance. The center also clarified discharge limits of malachite green, which is permitted under the Service's Investigational New Animal Drug Permit (INAD). Washington, Oregon, and the U.S. Environmental Protection Agency set limits on discharge levels of malachite green at selected Federal and State hatcheries listed under the Service's INAD. The agencies ruled that hatcheries under their jurisdiction can use malachite green but limit its discharge.

Feed and Nutrition

In cooperation with the Tunison Laboratory of Fish Nutrition, the Fish Culture Research Laboratory—Lee-town compared the Service's contract formulation Atlantic salmon diet with a commercial trout grower's formulation for effectiveness in striped bass. Striped bass had

superior growth rates but unusually high tissue lipid content when maintained on the salmon diet. The trout formulation, however, caused extensive histological liver changes that may affect liver function. A survey of striped bass, produced at several Federal fish hatcheries, indicates that most of the fish reared on trout-type diets have abnormal liver tissue structure. Long-term effects of these changes on the fish are unknown.

Sources of fish oils are scarce because of the tremendous demand for their use in human pharmaceutical preparations and the worldwide expansion of aquaculture. Scientists at the Tunison Laboratory studied the extent to which the content of 3 carbon polyunsaturated fatty acid in farmed trout might be affected by different levels of linseed oil in a nutritionally balanced diet. The different dietary treatments did not affect fish weight gain, feed conversion, or overall body composition during the study period. However, significant changes in fatty acid composition suggested increased levels of a particular dietary fatty acid can increase fatty acid in the tissue.

In another study, scientists at the Tunison Laboratory also used juvenile Atlantic salmon to test the efficacy of several substances that have accentuated the feeding response of fishes in laboratory tests. Results indicated that none of the

treatments increased the feeding efficiency or growth of these fish, but trimethylamine and glutamic acid seemed to act as feeding deterrents. Only addition of the amino acid glycine increased food consumption. This deterrent effect of trimethylamine suggests that the fish were sensitive to it as an indicator of the freshness of their feed. This possible sensitivity may play a role in the aversion that salmonids and other fish exhibit toward highly oxidized meals and oils.

An electronic demand fish feeder was constructed and tested at the Hagerman Field Station of the Tunison Laboratory. The feeder is activated when a fish accepts an artificial pellet and pulls a line attached to the electronic triggering device that releases a predetermined number of feed pellets. Following the release of feed, a refractory period occurs during which more feed will not be released. Therefore, the feed wasted from excessive activity is minimized. The demand feeder documents feeding behavior by recording the time of day at which feedings occur. Because the feeder can be used with fish that weigh as little as 0.5 gram it aids in nutrition research with smaller fish than previously possible with other feeders. Use of the feeder resulted in 20% better growth in chinook salmon and rainbow trout than conventional feeding methods.

Federal fish hatcheries are raising striped bass to stock streams and bays along the eastern coast and restore populations that have been depleted by overfishing and habitat destruction. To feed fry, hatchery managers must provide an abundant supply of zooplankton in hatchery ponds. High densities of zooplankton are produced by proper application of fertilizers. Scientists at the Fish Farming Experimental Laboratory in Stuttgart, Arkansas, compared survival and growth of striped bass fry, water quality, and zooplankton production from fertilization with 2% nitrogen in rice bran with fertilization with 7% nitrogen in cottonseed meal. Fertilization with rice bran was more effective and 67% less expensive than fertilization with cottonseed meal.

Water Quality

Although fish grow well and thrive at the New York State Cedar Springs Fish Hatchery, recent attempts to use this hatchery for spawning have been unsuccessful, especially with lake trout and Atlantic salmon. Survival of eggs to the eyed stage—when the eyes are visible—was often less than 30%. At a neighboring hatchery, survival was much better. Two obvious differences between the hatcheries were the chemical composition of the water supplies and initial degrees of hardness of the water-hardened eggs spawned in them. In an experimental procedure, survival of eggs was very low when hardened in water with 520 parts per million calcium (typical of Cedar Springs) for a few hours. In comparison, survival of eggs significantly increased when they were initially water-hardened in softer water similar to that from the neighboring hatchery. Incubation of eggs in high-calcium water after the initial water-hardening period did not significantly af-

fect survival. In another experiment on water-hardening of rainbow trout eggs, survival increased significantly when eggs were water-hardened. This occurred in either softer water or in high-gypsum water softened by ion-exchange to markedly reduce calcium but not sulfate content. Therefore, high concentrations of calcium alone during water hardening seem to account for the increased mortality of fish embryos.

Nitrite toxicity or brown blood disease can be a serious fish disease problem with intensive fish production in ponds. Scientists at the National Fisheries Research Center—Gainesville determined that both calcium chloride and sodium chloride can reduce the toxicity of nitrite to striped bass. In a chloride-to-chloride comparison, calcium chloride dissolved in the water was more than twice as effective as sodium chloride at reducing the toxicity of nitrite to striped bass.

Scientists at the Southeastern Fish Cultural Laboratory—Gainesville determined that salt can greatly reduce transport stress and speed recovery in striped bass. Addition of 1% salt to the water used for transport and recovery increased striped bass survival, decreased plasma cortisol and blood glucose concentrations, and reduced ion imbalances normally seen during transport of striped bass. The addition of 0.1% calcium chloride, a practice recommended by some aquaculturists, did not reduce transport-induced stress.

Culture Methods

Commercial fish farmers have recognized the void in the commercial fish market from the collapse of wild striped bass stocks. As a result, methods for the production of striped bass and hybrids between striped and white bass are being developed. Because of the difficulty in obtaining female striped bass for brood purposes, the reciprocal

cross-hybrid (male striped bass × female white bass) is often used. However, the extremely small size of the reciprocal fry causes a problem. These fry are too small to ingest the larger zooplankton in most fertilized ponds and may depend on small plankton that are available for only a short time after ponds are filled. Fish culturists sometimes use Masoten, an insecticide, to control development of populations of larger zooplankton and thereby prolong the period that smaller zooplankton dominate the pond. The insecticide may also promote survival of the reciprocal fry by reducing predation by aquatic insects. Results from experiments at the Fish Farming Experimental Laboratory at Stuttgart, Arkansas, suggest that Masoten reduces mortality in reciprocal-cross-striped bass cultures.

Staff of the Fish Culture Research Laboratory at Leetown, West Virginia, are investigating dietary requirements of striped bass larvae. Larvae grow significantly larger on *Artemia*—newly hatched brine shrimp larvae—that are supplemented with fatty acids than on a normal *Artemia* diet. Because most hatchery production of striped bass is conducted in ponds, research was conducted at four Federal fish hatcheries on fertilizer treatments and the first phase of striped bass production. Water chemistry, zooplankton populations, and fish production were monitored and compared between ponds receiving a modified intensive fertilization regime and the standard hatchery production methods. The resultant widely divergent water chemistries demonstrate the need to optimize fertilization strategies for each facility.

The Atlantic States Marine Fisheries Commission prescribed that all hatchery fish must be tagged before they are placed into Chesapeake Bay by the Emergency Striped

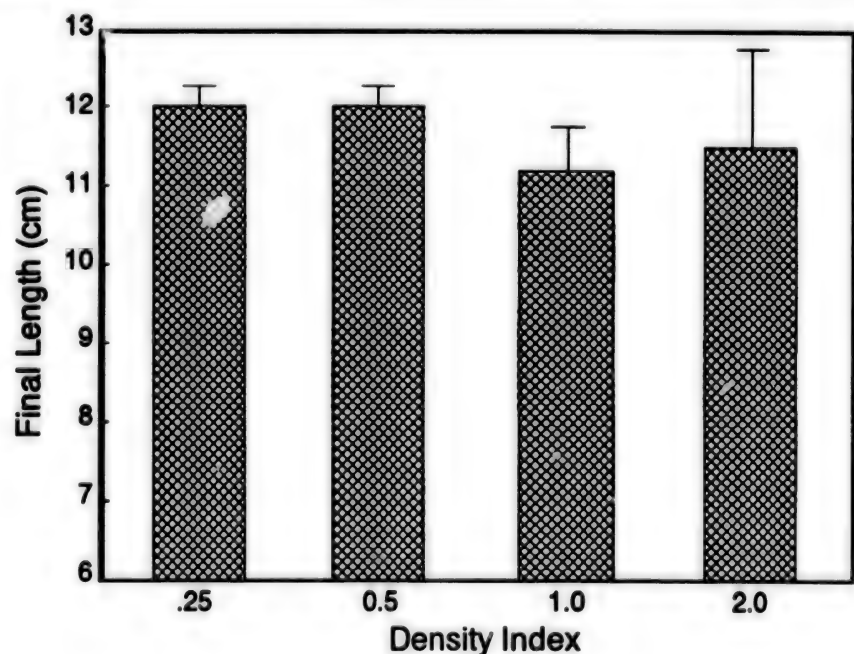
Bass Restoration Program. About 3.3 million juvenile striped bass have been tagged with binary-coded wire microtags and released since 1985. The Fish Culture Research Laboratory assisted in this effort by tagging about 100,000 Phase-I striped bass for release in the Patuxent River and, later, by providing information on daily mortality rates and movement patterns away from stocking sites. It also investigated both short-term and long-term retention of tags in Phase-I and Phase-II striped bass and monitored 2-week poststocking survival in cages at stocking sites. During 1989, tag retention after 2 weeks in on-site cages averaged 89% for Phase-I and 95% for Phase-II striped bass. Long-term retention averaged 96% for fish tagged as Phase-I juveniles and maintained in a raceway for 18 months. Two-week survival rates in cages indicated that salinity of the stocking site greatly influenced survival of the fish after stocking. Stocking at sites where salinity was greater than 3 parts per thousand significantly improved survival.

Development of filamentous algae and rooted vegetation in ponds with striped bass cultures is a major problem for hatchery managers. This nuisance vegetation reduces plankton by competing for available dissolved nutrients. Because the fingerlings cannot be harvested efficiently or without heavy fish mortalities unless the vegetation is prevented from growing or removed before harvest, filamentous algae and rooted vegetation cause much additional work and expense for hatchery personnel. This removal must be done by hand or by the use of expensive herbicides. A two-pond polyculture technique was developed at the Fish Farming Experimental Station, in Stuttgart, Arkansas, in which water is circulated between a turbid catfish pond and a fry pond; this technique controls both filamentous algae and rooted vegetation. Scientists compared the percent of cover of filamentous algae and rooted vegetation in four striped bass ponds in the two-pond polyculture system with four striped bass monoculture ponds. By the end of 10 weeks, the

amount of unwanted vegetation was significantly less in the polyculture ponds and did not interfere with seining operations. The polyculture technique also reduced the amount of fertilizer needed to grow plankton in the fry ponds.

Scientists from Memphis State University, in collaboration with the Southeastern Fish Cultural Laboratory, have made significant breakthroughs in control of gender in channel catfish. Because male catfish grow faster than females, production of all-male populations can result in as much as 20% greater profits for commercial catfish farmers. Through use of a combination of genetic techniques, scientists have produced a number of super-male catfish. These super-males produce all male offspring when they are mated to normal females. As soon as an early screening technique for determining genotype of young fish is developed, new catfish farmers can begin commercial production of all-male fingerlings within 4 years.

Final length of lake trout reared for 120 days at four different densities. Figure by G. Pardue.



Efficient design and management of fish production systems require an estimate of carrying capacity. Researchers at the National Fishery Research and Development Laboratory developed a site-specific production capacity assessment (PCA) to assist with the design, planning, and operation of a hatchery. The assessment defines fish production limits of a water supply or the capacity of a rearing system based on the amount of oxygen that may be removed. In Production Capacity Assessment studies with oxygen and air added to the water supply, fish production more than doubled fish production in un-aerated water. A study at the National Fishery Research and Development Laboratory demonstrated that through use of the Production Capacity Assessment, fingerling lake trout can be reared at four times the density recommended without significantly affecting their growth or survival.

Wildlife Propagation

Populations of some wildlife species continue to decline despite increased habitat preservation and management, field research, and enforcement of protective regulations. For these species, numbers can often be increased through captive propagation. Several endangered species and their surrogates are maintained for captive propagation and research at various Fish and Wildlife Service locations. By studying the physiology, behavior, and other aspects of the biology of these species, scientists are able to develop new techniques to maximize reproduction in captivity and ultimately produce appropriate numbers for release in the wild.

Whooping Cranes

Only 211 whooping cranes remain in the world. A flock of 143 birds winters along the Texas coast at the Aransas National Wildlife Refuge and breeds at the Wood Buffalo National Park in Canada. An additional 13 birds make up the Rocky Mountain Experimental Flock that summers in Idaho and winters in New Mexico. This second wild flock was developed from eggs transferred from wild nests in Wood Buffalo National Park and Patuxent Wildlife Research Center to wild sandhill crane nests. The remaining 55 cranes are in captivity. There are now 32 whooping cranes at Patuxent, 22 at the International Crane Foundation, and 1 adult male at the San Antonio Zoo. In autumn 1989, a second captive whooping crane flock was established at the International Crane Foundation (ICF) in Baraboo, Wisconsin. A portion of the Patuxent flock (22 birds) was moved in 3 separate air shipments to ICF to minimize risks to the gene pool from catastrophic events (such as disease) and to separate propagation responsibilities (ICF) from research responsibilities (Patuxent). Every effort was made to divide the flock according to recognized genetic management guidelines so that known family lines will be represented at both sites.

In 1989, five whooping cranes laid 19 eggs at Patuxent. Fourteen eggs were fertile, nine hatched, and eight chicks fledged. Six viable eggs from wild nests in Canada were transferred to Patuxent where all six hatched and three fledged. These eleven fledged whoopers represent a record annual total.

Six pairs of whooping cranes successfully reared sandhill crane chicks in 1989. One of the pairs accepted a fake egg placed in a nest. A viable egg, later substituted into the nest, was hatched and the chick

was reared. Wild sandhill crane pairs that successfully rear chicks are more likely to stay together and be productive in ensuing years. Researchers hope that by having captive whooping crane pairs rear sandhill crane chicks, the birds will form stronger pair bonds, feel more comfortable in and aggressively defend their territories, lay more eggs, and eventually rear their own chicks that can be released into wild habitats.

Mississippi Sandhill Cranes

To bolster the remaining wild population of Mississippi sandhill cranes, such cranes reared at Patuxent have been transferred to the Mississippi Sandhill Crane National Wildlife Refuge for acclimation and release since 1981. In Mississippi, Patuxent birds have formed pair bonds with each other or with wild birds, and have nested and reared young. By 1989, Patuxent birds accounted for one-third to one-half of the population in Mississippi.

In 1989, 14 captive female Mississippi sandhill cranes laid 76 eggs at Patuxent. Two fertile eggs were transferred to wild nests in Mississippi to replace nonviable eggs. Fifty-four fertile eggs were retained at Patuxent; 42 of these hatched and 33 chicks fledged. In addition, two viable eggs from the refuge were transferred to Patuxent to bolster genetic diversity in the captive flock. Both eggs hatched and the chicks were fledged.

Alternative crane-rearing techniques were tested for their effects on survival of birds in the wild. Twelve of the Mississippi sandhill chicks hatched in 1989 were costume-reared (a human in crane costume) and 17 were foster parent-reared, the method used in most previous years. Beginning in 1986, hand-rearing techniques for cranes were changed to promote parental and sexual imprinting on adult



Endangered Mississippi sandhill crane chicks were fed with a taxidermically prepared crane head. Photo by D. Ellis.

cranes rather than on human caretakers. By 1989, hand-rearing techniques included the use of stuffed crane brooder models, stuffed crane-head feeding models, and a live crane penned next to chicks. Rearing was further refined to include frequent interaction with a human in crane costume. Three release cohorts (parent-reared, costume-reared, and mixed) were formed a month before transfer of cranes to Mississippi. In November, 29 young birds, more than twice as many as ever before in one year, were sent to Mississippi for

acclimation and release. The birds were color-marked and some were radio-tagged. Data on behavior and survival between the cohorts is being collected and will help identify the best methods for rearing birds for release. Two months after release, all of the hand-reared birds survived, and all but two parent-reared birds survived. Human avoidance tests 1 month after release revealed that costume-reared birds and parent-reared birds are comparable in wildness.

Genetic Diversity and Relatedness in Cranes

Knowledge of existing genetic diversity and individual relatedness is necessary to manage a captive population and to establish viable wild populations. For cranes, Patuxent scientists based estimated genetic diversity on protein electrophoresis of blood followed by histochemical localization of specific allozymes. Estimates were obtained for several crane species to determine if genetic diversity in whooping and Mississippi sandhill cranes is less than the diversity in

other species. Diversity was less in whooping cranes than in Florida sandhill cranes, and less in Mississippi sandhill cranes than in any of the other 14 crane species. In addition, maintenance of diverse blood types in a population preserves a higher level of immune response and consequently a greater capacity to resist disease. Blood typing of sandhill and whooping crane populations is proceeding at the Patuxent Wildlife Research Center. Blood typing reagents have been taken from 19 sandhill cranes and tested against 20 of their offspring. Once the blood typing reagents are prepared, the captive whooping crane population will be tested for diversity.

Black-footed Ferret

The captive population of black-footed ferrets increased from 24 to 58 in 1988 and to 121 in 1989. This rate of increase is expected to meet the new recovery plan's objective of

200 breeding captive adults and a surplus for reintroduction in 1991. In 1988, the Wyoming Game and Fish Department moved some ferrets from its captive breeding facility to the National Zoo's Conservation and Research Center in Front Royal, Virginia, and to the Henry Doorly Zoo in Omaha, Nebraska, to protect the species against catastrophic loss. A \$5,000 reward for a confirmed black-footed ferret sighting was offered in cooperating States in 1988 and was raised to \$10,000 in 1989. About 100 possible ferret sightings were reported each year to the National Ecology Research Center. Follow-up investigations were made on some sightings, and searches were performed in Alberta (Canada), Chihuahua (Mexico), Colorado, Utah, and Wyoming. Even with this intensive effort to locate additional ferrets, no wild black-footed ferrets were found. Based on ferret energetics and prairie dog dynamics, a model was completed to evaluate

the potential use of complexes of prairie dog colonies as reintroduction habitat for black-footed ferrets. The evaluation relies heavily on estimating numbers of active burrows in respective complexes. Because the density of active white-tailed prairie dog burrows was highly correlated with prairie dog counts, managers will be able to use the collected burrow data instead of actual counts of prairie dogs. With this system, scientists reevaluated the prairie dog complex formerly occupied by ferrets at Meeteetse, Wyoming. The decline of this complex of white-tailed prairie dog colonies by 50% in quantity from 1988 to 1989 was probably due to plague. Scientists also sampled and evaluated a large complex of black-tailed prairie dogs in Chihuahua, Mexico. Other State and Federal agencies used the system to evaluate six additional potential reintroduction sites.

Disease Management

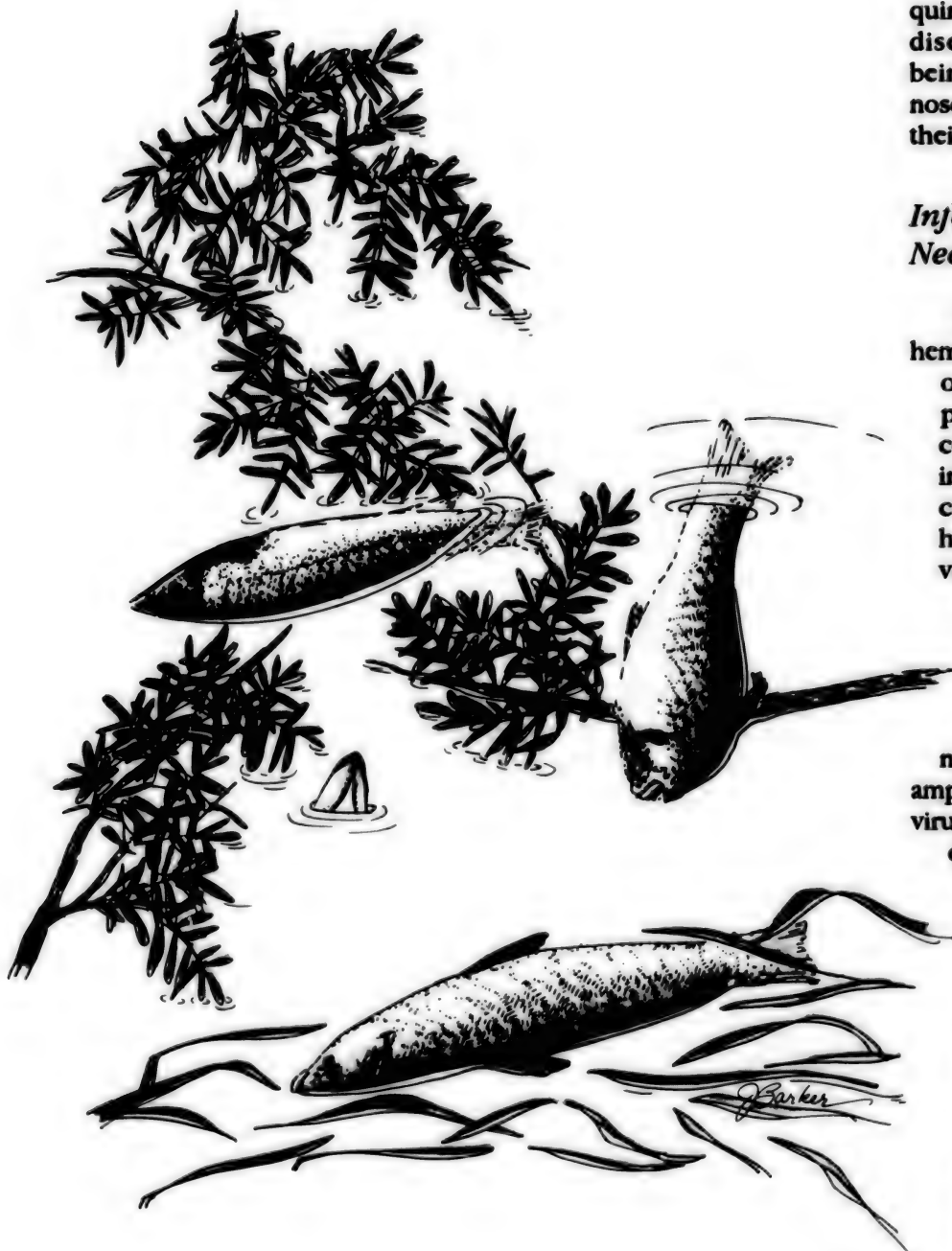
Fish Diseases

Successful culture of fishes requires rigorous control of infectious diseases. Extensive research is being conducted to detect, diagnose, and treat such diseases and their causative agents.

Infectious Hematopoietic Necrosis

The virus that causes infectious hematopoietic necrosis (IHN), a serious disease of juvenile salmonids, previously was detected by rather costly methods—first by isolation in fish cell lines, then by serological identification. A DNA marker has been developed to detect the virus directly in tissues of infected fish. The marker acts by reacting specifically with a portion of the nucleoprotein of the virus. Polymerase chain reaction, a new technique in molecular biology, amplifies the genetic material of the virus several million-fold, thus greatly enlarging the target of the DNA marker. These methods are extremely efficient in detecting the virus in infected cells, and their use in identifying infected fish is being evaluated.

Fishery scientists have developed a series of highly specific monoclonal antibodies, whose specific origin helps understand the antigenic makeup of IHN virus and determine if different strains exist. The antibodies are used to determine the surface structure of IHN virus. To date, the results from the use of these antibod-



ies indicate the existence of at least four strains of the IHN virus.

To learn more about the rate of IHN virus evolution and the extent of its genetic diversity in North America, researchers are using a new genetic fingerprinting technique based on T1 ribonuclease oligonucleotide analysis. The genetic material of each virus strain is digested into fragments that are then separated by electrophoresis, resulting in a unique "fingerprint" for each strain. Comparison of fingerprint samples from the same location over a period of years gives a measure of the rate of genetic change in the viral population. The technique revealed that the virus is continually changing within river systems, and that degree of genetic difference increases with geographic isolation.

Viral Hemorrhagic Septicemia, a Newly Introduced Pathogen

Viral hemorrhagic septicemia (VHS) is the most serious disease affecting European salmonids. VHS was unknown in North America until 1988, when it was diagnosed in salmon homing to two locations in Washington. Personnel at the National Fisheries Research Center—Seattle confirmed the diagnosis of VHS virus with extensive immunological and electrophoretic tests and electron microscopy. The center constructed a quarantine facility and, using six salmon and trout species, began research on comparative susceptibility, pathology, and rapid detection methods.

Through cell and tissue culture technique, the VHS virus is detected by its reactivity with specific antibodies. Previously, by using rabbit antisera, the three known VHS serotypes were distinguished but the neutralizing activity is low. The National Fish Health Laboratory—

Leetown developed hybridoma cell lines that secrete antibody specific for VHS virus. The antibody from this cultured cell line improves on live rabbit antiserum in that it reacts vigorously with all three serotypes of the VHS virus. Furthermore, it will not interact with other viruses, and it reacts as well with inactivated as with fresh material. Hybridoma cell lines provide a continuous supply of specific antibody, and can be used in immunological rapid-detection systems such as the enzyme-linked immunoblot assay and fluorescent antibody tests.

Epizootic Mortality in Hatchery Lake Trout Caused by a Herpesvirus

Research at the National Fish Health Research Laboratory identified a herpesvirus as the cause of catastrophic losses of lake trout in hatcheries of the Great Lakes basin. The virus seems to affect only lake trout and splake (lake trout-brook trout hybrids), and thus far it has not been detected in brook, brown, and rainbow trout and Atlantic salmon. The virus targets fish skin, which dies and sloughs in patches. Attempts to isolate the virus in cell culture have been unsuccessful, although it can be concentrated by a complicated purifying process from the skin of infected fish and is seen with the electron microscope.

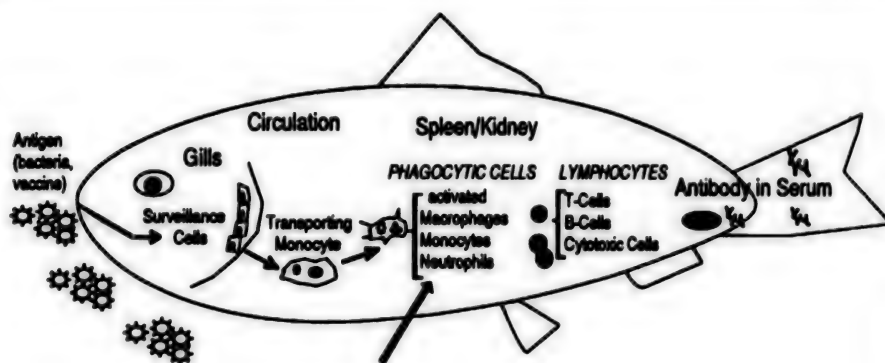
Bacterial Kidney Disease

To determine the effects of bacterial kidney disease (BKD) infection on survival of juvenile chinook salmon during transportation, researchers monitored prevalence and severity of BKD in spring chinook smolts at collection facilities, determined transmission of BKD among transported fish, and followed downstream migration of transported and nontransported smolts with either light or heavy BKD infection. Al-

though obviously diseased fish at dams ranged from 1 to 6% of captures, immunosorbent tests demonstrated that BKD bacteria were present in 86 to 96% of the fish. Sixty-five percent of these fish had very light infections. The greatest prevalence and severity of BKD was in fish taken as they entered the ocean.

Columnaris Disease

Columnaris disease causes significant losses of cultured striped bass. Immunological studies indicate the columnaris bacterial agent has low antigenic effect on host sera, which makes early detection difficult. Attempts at electrophoretic detection are useless because the proteins of the bacterium vary with the culture medium and the organism also lacks enveloping capsule material and lipopolysaccharides. Immunoassay of rabbit antisera indicated that although many of the bacterial proteins are antigenic, but they do not offer protection to the fish. A breakthrough in columnaris disease research was achieved at the Fish Farming Experimental Laboratory with development of an improved gelatin-based culture medium. Identification is now rapid once colonies develop. The culture medium contains neomycin sulfate, an antibiotic which suppresses other bacteria. The medium also acts as a test substrate—the gelatin component becomes opaque as it is digested by gelatinase, a diagnostic enzyme reaction among bacteria. The columnaris bacteria also produce the enzyme chondroitinase, which is demonstrated by removal of a colony along with a plug of medium, and testing for the enzyme. Finally, addition of a solution of neutral red to a columnaris colony stains it red. These three tests,



Schematic diagram of the immune pathway in a fish after vaccination. Soon after immunization by injection or bath, the neutrophils in trout blood become activated—and thus are good indicators of the ability of the fish to fight diseases. Specific immune response indicators such as antibodies develop later in the immune response cycle.

combined with unique colony morphology and color, allow rapid positive identification of the columnaris bacterium.

Immunogenetic Properties of Aeromonas salmonicida

Aeromonas salmonicida, the causative agent of furunculosis, is a major bacterial pathogen in cultured salmonids. Virulent forms have an envelope of antigenic protein around the cell, which makes them good candidates for developing disease-control vaccines. Four antigenic forms of *A. salmonicida* have been characterized based on immunogenicity (immunizing effectiveness) of cell envelope somatic antigens, namely, the lipopolysaccharide O-antigen and the protein A-layer. Bacterial cell suspensions (bacterins) against four isotopes were produced: O^+/A^+ , O^-/A^- , O^+/A^- , and O^-/A^+ . When injected alone into the abdominal cavity these bacterins afforded no protection against infections. However, administered with an adjuvant—an ingredient that modifies or enhances action of the principal ingredient— O^+/A^- afforded some immunity. Vaccination with the O^+/A^+ phenotype resulted in still better protection. The study confirmed that lipopolysaccharide in the fu-

runculosis bacterial envelope is the major factor producing an immune response when injected along with chemical modifiers.

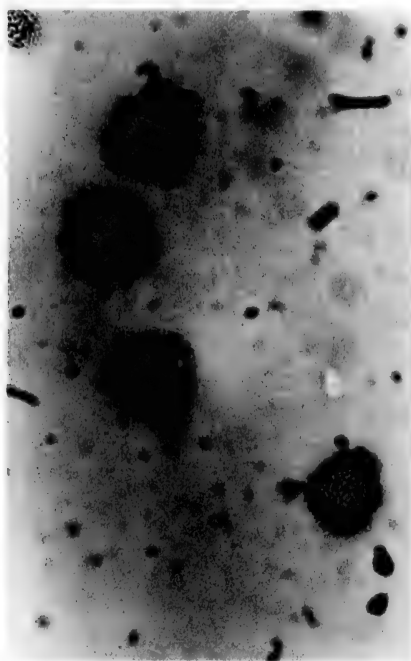
Monitoring of Neutrophils Indicates Effective Vaccination

The nitroblue tetrazolium (NBT) assay indicates the level of neutrophil activity, a measure of response to disease exposure—as well

as effectiveness of a vaccine in producing an immune response. The assay is made by placing a blood sample on a glass slide and treating it with NBT. Activated neutrophils adhere to the glass and are stained by the NBT. Effectiveness of vaccination is indicated by an increase in the number of activated cells. This can be done as early as 2 days after vaccination. The assay also can be used as an indicator of toxicity.

Blood of a rainbow trout is being sampled in a laboratory experiment to test for the numbers of blood neutrophils. The fish was immunized 2 days earlier; the numbers of neutrophils adhering to a glass slide is correlated with activation of the immune response. Photo by H. M. Stuckey.





These neutrophils, taken from the blood of a rainbow trout and stained with NBT dye, show increased activity, as indicated by the presence of dark-blue granules in their cytoplasm. Photo by H. M. Stuckey.

Protozoan Parasites

The threatened greenback cutthroat trout is cultured in Colorado. The recent diagnosis of the whirling disease sporozoan, *Myxobolus (Myxosoma) cerebralis*, in cultured fish in Colorado raised the question of susceptibility of the greenback cutthroat trout to the parasite. Tests have shown this trout not only susceptible to infection by *M. cerebralis*, but subject to greater mortality than rainbow trout—even at lower whirling disease spore density. Whereas mortality was 3% in rainbow trout, it was 26% in greenback cutthroat trout. Although infected greenback cutthroat trout ate less and grew more slowly, no deformities were observed.

Immunization against parasitic ciliates by exposure to a free-living form was demonstrated in striped bass. Experimental fish were immunized by immersion in a suspension culture of the nonparasitic ciliate *Tetrahymena thermophila* and given a booster exposure 2 weeks later. The

fish were maintained for 4, 6, or 8 weeks and then exposed to the pathogenic ciliate *Trichodina* sp. Survival increased with length of time after immunization.

Effects of Nutrition on Disease Resistance in Channel Catfish

Poor nutrition is known to lower disease resistance in channel catfish by interfering with macrophage function (including white blood cells) and immune response. Because commercial feeds often use beef tallow and other animal fats high in saturated lipids, and may not provide optimal levels of essential fatty acids for fish, dietary lipids were evaluated at the Georgia Cooperative Fish and Wildlife Research Unit. For 4 months, channel catfish were fed experimental diets with lipids from one of three sources: beef tallow (high in saturated and mono-unsaturated fatty acids), soybean oil (high in polyunsaturated n-6 fatty acids), and menhaden oil (high in long chain polyunsaturated n-3 fatty acids). Fish

were then vaccinated against *Edwardsiella ictaluri*, a serious bacterial pathogen of channel catfish. The subsequent ability of head kidney macrophages to phagocytize and kill the bacteria was compared among the three groups. Before immunization the macrophage phagocytic ability was not different among the groups, although the killing ability of macrophages from fish fed menhaden oil was significantly higher. After vaccination, all groups had circulating antibodies against the bacteria. The bactericidal activity of the macrophages increased in fish fed menhaden oil or soybean oil, but not in fish fed beef tallow. The study revealed that lipid composition of diets is an important factor in the immune response and macrophage function in fish. Channel catfish fed beef tallow or other saturated animal fats may not respond optimally to vaccination.

Wildlife Diseases

Research Facility Dedicated

A new 4.5-million dollar Research and Tissue Isolation Building was dedicated in August 1990 at the National Wildlife Health Research Center in Madison, Wisconsin. The contemporary design of the building provides center personnel with modern facilities for handling infectious materials and conducting live-animal research on infectious diseases without endangering themselves, the community, or the environment. Containment and controlled access distinguish the facility.

Entering and leaving the isolation area by people and products are tightly controlled. Inside the isolation area, people are required to change clothes before moving from one room to another. On leaving the facility, everything—including air,



Waterfowl that have died from avian cholera being prepared for incineration in Nebraska's Rainwater Basin.

water, laboratory materials, supplies, and people—is treated to avoid environmental contamination. These treatment procedures require the use of many containment techniques from air filters and negative pressure systems to autoclaves and, for people, automatic showers. These extensive containment procedures ensure that center personnel will have a safe work environment from which to face and meet the challenges of research in wildlife disease for many years ahead.

Wildlife Disease Outbreaks and Die-offs

The National Wildlife Health Research Center received 352 reports of wildlife disease die-offs since the 1987-88 report. Primary causes of death included avian botulism, avian cholera, toxins, and lead. Type C botulism outbreaks were widespread and caused the greatest number of deaths; an estimated 80,000 birds died in 101 die-offs in 27 States. The single greatest botulism die-off occurred during fall 1988 when an esti-

mated 25,000 waterbirds died on the slowly receding Great Salt Lake in Utah. Mallards were the most commonly affected species across all flyways, but significant numbers of northern pintails, green-winged teal, and American coots were affected in the Pacific and Central flyways.

Fifty-one avian cholera outbreaks in 14 different States resulted in about 47,000 deaths. Avian cholera was most common among snow, Canada, white-fronted, and Ross' geese, northern pintails, and mallards. Reported avian cholera losses

decreased somewhat in western states with traditionally endemic problems. Many single mortality events involving large numbers of birds occurred in the Mississippi and Central flyways. Avian cholera occurred for the first time in Minnesota where 7,600 Canada geese died. In the Rice Belt of Texas, an area that averages 100 bird deaths a year from avian cholera, an estimated 7,000 geese died in 1988 and another 7,000 died in 1989.

The Fish and Wildlife Service, Texas Parks and Wildlife, and other concerned agencies and citizens joined together in an effort to control an outbreak of avian cholera in the Texas Rice Belt. *Photo by The Houston Post/I. Strickstein.*



Over 47,000 carcasses were counted in die-offs caused by oil spills. This number represents 94% of the reported total deaths due to toxic agents. The most commonly recovered species were common murre; surf, common, and white-winged scoters; western grebes; auklets; murrelets; and gulls. Aflatoxicosis and other mycotoxicoses, caused when waterfowl ingest fungal toxins in moldy grains, were diagnosed in six Texas die-offs.

Lead poisoning continued in California, Iowa, Rhode Island, and Wisconsin. First-time outbreaks of lead poisoning occurred in several drought-stricken areas where low water levels increased availability of lead shot.

Disease Diagnostic Services

The National Wildlife Health Research Center continued to process large numbers of carcasses and tissue specimens (Table). The primary users (62%) were Fish and Wildlife Service personnel. State conserva-

tion agencies submitted 16% of the specimens and the remainder (22%) were submitted collectively by other Federal agencies, local governments, universities, and private sources. Specimens were received from 47 States, the District of Columbia, and Puerto Rico.

Avian Botulism Research

Environmental Conditions Associated With Outbreaks

Avian botulism is caused by ingestion of toxin that is produced by the bacterium *Clostridium botulinum* and is a major cause of death in waterfowl and shorebirds. Losses of tens of thousands of birds in a single outbreak are not unusual, and annual continental losses can reach hundreds of thousands. Environmental conditions that favor botulism outbreaks are poorly understood. The National Wildlife Health Research Center and Northern Prairie Wildlife Research Center conducted research

to identify environmental factors that may trigger or be associated with botulism outbreaks. At the Sacramento National Wildlife Refuge in California, botulism occurs regularly in some wetlands but rarely or never in apparently similar wetlands. Water quality may play a role in the occurrence of botulism; wetlands flooded with agricultural drainwater seemed to have greater losses than those flooded with Sacramento River water. Various soil and water parameters with potential influence on growth and toxin production of *C. botulinum* were measured. Game-farmed mallards were placed in 4-acre enclosures to monitor the site-specific occurrence of botulism. Water source (agricultural drainwater versus Sacramento River) was not related to the occurrence of botulism. In contrast to many common beliefs about botulism, outbreaks at study sites were not dependent on shallow, stagnant water or the presence of feather edges. Botulism occurred in deep, well-oxygenated water. The potential roles of other

Wildlife disease specialists collect fly maggots to assess the role of these organisms in avian botulism outbreaks. Decomposing bird carcasses are one source of type C botulism toxin, the cause of avian botulism in waterfowl and shorebirds. Upon death of waterfowl, *Clostridium botulinum*, a spore-forming bacteria frequently found in intestinal tracts, germinates and produces botulism toxin. Photo by T. E. Rocke.



environmental variables in botulism outbreaks, such as temperature, pH, oxidation-reduction potential, and conductivity, are being analyzed. Microbial and invertebrate populations are being studied to identify their potential role in botulism outbreaks. An understanding of these environmental factors and their role in triggering botulism outbreaks might lead to wetland management strategies that reduce the risk of avian botulism.

Ecological Interactions at the Microbial Level

Studies of community dynamics and population ecology have traditionally focused on higher life forms. For example, predation, competition, commensalism, and chemical inhibition among many plant and animal populations affect community structure. Likewise, similar interactions among microbial communities have profound effects on the dynamics of microbial populations, including disease-causing microorganisms. The National Wildlife Health Research Center and the University of Wisconsin-Madison have studied interactions among common wetland microbes and their influence on avian botulism outbreaks. *Clostridium botulinum* (type C), the bacteria that causes avian botulism, is widely distributed in marsh sediments. Several soil microorganisms have been shown to produce substances such as antibiotics and bacteriocins that inhibit other microorganisms. Such microbial interactions in marshes may influence the growth of *C. botulinum* or production of botulism toxin.

Sediment samples from the Sacramento National Wildlife Refuge in 1986 and 1987 were cultured for *C. botulinum* and other bacteria. Laboratory tests revealed the presence of bacteria that inhibit the growth of

botulism. At least 15 species of bacteria were demonstrated to inhibit the growth of the type C botulism bacterium. This knowledge has future application in the control and prevention of avian botulism; for example, wetlands could be managed to favor microorganisms that suppress the growth of *C. botulinum* and deter the production of botulism toxin.

Risk Assessment Modeling

The National Ecology Research Center, in cooperation with the University of Saskatchewan, is developing a model to identify botulism risk factors of wetlands. Predictions of favorable conditions for botulism outbreaks will allow refuge managers to take timely preventive measures. Testing of the model in the field and comparing results with information on actual botulism mortality information indicate that the model provides a good general assessment of risk for some individual wetlands but poor differentiation of risk among units in a large wetland complex. This type of risk assessment is adequate for many waterfowl migration areas, but future refinements must address assessment of differential risk among wetland units. These refinements have to be based on further research and understanding the epizootiology of avian botulism.

Lead Poisoning From Environmentally Persistent Lead Shot

Nationwide compulsory use of nontoxic (steel) shot for waterfowl hunting in the United States by 1991 will eliminate additions of lead shot to waterfowl habitat. However, accumulation of lead shot from decades of intensive hunting, in combination with habitat characteristics that keep spent shot near the surface, will pro-

vide a persistent source of lead shot in many areas.

Studies by the National Wildlife Health Research Center at the Sacramento National Wildlife Refuge in California revealed that the density of lead pellets exceeded 850,000 per acre in a heavily hunted wetland. After one season of steel shot use, 1% of recovered pellets were steel. Another wetland unit that had never been hunted, but was adjacent to an area that had been hunted until 1973, had a lead pellet density of 70,000 per acre. Sentinel mallards confined to three wetlands with densities of lead pellets ranging from 6,375 to 850,000 per acre, showed increasing rates of lead exposure. The seasonal (90-day) mortality rate in sentinel birds from the high-pellet density unit was 23.9% during summer and fall and 8.6% during winter and spring.

Lead poisoning in Canada geese of the Eastern Prairie population has been studied cooperatively by the National Wildlife Health Research Center and the Wisconsin Cooperative Wildlife Research Unit. During fall migration, geese that leave the breeding grounds along the Hudson Bay first encounter lead pellets at staging areas in Manitoba, where 7% of live-trapped geese showed evidence of lead exposure. At the Lac Qui Parle Wildlife Management Area in Minnesota, fewer than 2% of geese exhibited exposure to lead but 4.5% of the geese that arrived on wintering grounds at Swan Lake National Wildlife Refuge in Missouri had been exposed. These two areas have been steel shot zones since 1980 and 1978, respectively. Despite almost 10 years of shooting steel shot, lead was still available to geese at Swan Lake; birds exposed to lead increased from 4.5% before the hunting season to 11% by mid winter, and decreased to 5% in late winter. Examination of carcasses revealed that lead poisoning was still the most frequent cause of nonhunt-



Wildlife pathologist performing an autopsy on an immature golden eagle at the National Wildlife Health Research Center—Madison. Photo by J. Runningen.

ing mortality at Swan Lake (67% of carcasses) and Manitoba (55%), but accounted for only 11% of the deaths at Lac Qui Parle.

Parasite Studies

The New York Cooperative Fish and Wildlife Research Unit studied the distribution of urban and suburban raccoon populations and the prevalence of patent *Baylisascaris procyonis* infections in them. The prevalence of this infection was highest in September, October, and November and was significantly higher in juvenile males than in other age classes by sex.

In another study, researchers at the Oklahoma Cooperative Fish and Wildlife Research Unit, in cooperation with Oklahoma State University, completed a 3-year survey of seasonal changes in tapeworms, roundworms, and bots in small mammals in central Oklahoma habitats that had been affected by consistent use of herbicides. All parasites that required two hosts were affected by habitat changes from

herbicides, but parasites with direct life cycles were most sensitive to seasonality. Parasitological studies at the National Wildlife Health Research Center focused on detection and identification of parasites in waterfowl and endangered species specimens. Various species of birds and mammals collected on the Mississippi Sandhill Crane National Wildlife Refuge as part of an effort to determine the cause of tumors in cranes at the refuge, were also examined for parasites. Unexpected potentially zoonotic (that is, transmissible to humans) parasites were identified on some of these specimens.

Wildlife Disease Training Program

The National Wildlife Health Research Center conducted wildlife disease-training workshops for about 425 biologists from 13 State conservation agencies. The program was supported entirely by Federal Aid funds and was designed to train field biologists to recognize

wildlife diseases and to learn techniques for handling disease problems. Center staff presented 2-day workshops to biologists and wildlife managers from Arizona, Idaho, Iowa, Louisiana, Maine, Minnesota, Nebraska, New Mexico, Oklahoma, and Utah. Shorter sessions were conducted for Michigan and North Dakota personnel. A workshop in Puerto Rico was attended by more than 70 island biologists. Agendas for the wildlife disease workshops were coordinated with respective participants to ensure that local needs and problems were adequately addressed. For example, considerably more material on diseases of large game, upland game birds, and furbearers were addressed in programs for State biologists, whereas programs for Federal biologists emphasized waterfowl. Wildlife disease specialists from universities and various State agencies, such as the Southeastern Cooperative Wildlife Disease Study, were recruited as instructors to provide specialized expertise.

Center wildlife disease specialists conducted workshops for about 170 Fish and Wildlife Service field personnel from Regions 3 and 4. Additional workshops provided training to Law Enforcement and Environmental Contaminants personnel. Another 30 people from the Bureau of Indian Affairs participate annually in a wildlife disease workshop. Center staff also provided in-house training on a one-on-one basis for university faculty and students and for others with special needs in wildlife disease.

Technical Assistance in Animal Care

During 1989 and 1990, the National Wildlife Health Research Center assisted six Region 8 research centers with animal care and use needs. This assistance included helping with anesthesia and surgical techniques, captive animal management, blood and tissue collections, euthanasia methods, and Animal Care and Use Committee procedures and protocol reviews. In addition, the center assisted Region 1 with the capture of Hawaiian amakihi; Region 2 with care and treatment of injured whooping cranes; and Region 5 with a workshop for State biologists on immobilization techniques. Numerous requests for assistance from other Federal and State natural resource agencies, various municipalities, and private institutions were also addressed.

Table. *Number of specimens examined at the National Wildlife Health Research Center.*

	Fiscal year 1988	Fiscal year 1989
Carcasses	1,699	1,695
Individual tissue samples	1,771	1,528

Chemical and Drug Registration

The Service is required to register with the U.S. Food and Drug Administration (FDA) all chemicals used for fish disease treatments. The National Fisheries Research Center—La Crosse is responsible for chemical registration; other Service laboratories assist as required.

Residues of Chloramine-T in Rainbow Trout

Bacterial gill disease causes great losses in trout and salmon hatcheries nationwide. Chloramine-T controls bacterial gill disease in cultured salmonids, but must be registered with FDA as a disease-control chemical if used on animals cultured for food. One requirement for registration is an evaluation of the clearance (elimination) for chemical residues in treated fish. A high-performance liquid chromatography method has been developed for simultaneous analysis of chloramine-T and its primary decomposition product, *p*-toluenesulfonamide, in water and fish tissues. The center uses gel permeation chromatography to prepare samples for high-performance liquid chromatography. Chloramine-T is unstable in fish tissues and residues are present as *p*-toluenesulfonamide. Sensitive limits of detection developed for water and fish tissues (0.01 part per million) will ensure detection of the material during later clearance studies.

A pilot study evaluating the uptake, distribution, and elimination of ^{14}C -chloramine-T showed relatively slow uptake in rainbow trout. After transfer to fresh water, residue concentrations rapidly dropped to below detectable levels. Chloramine-T controls disease, and leaves only minimal chemical

residues, after an adequate withdrawal period (72 hours). When registered with FDA it may be safely used in fish culture.

Analytical Methods for Malachite Green

Malachite green dye is the most effective known chemical control for fungus infections in cultured fish. Its use has been restricted by the FDA, however, because it causes developmental anomalies. Selected fish hatcheries are permitted to use malachite green under an Investigational New Animal Drug Application permit issued by FDA. Its residues in water and fish tissue must be detectable as part of the information needed to maintain the Investigational New Animal Drug Application permit for the fungicide. Analysis of malachite green residues in solution is difficult because its colored form exists in equilibrium with two colorless forms, carbinol and leuco malachite green.

The La Crosse Center developed a high performance liquid chromatography method to detect malachite green and its breakdown products in water and fish tissues. Detection limits for each form of malachite green are less than 10 parts per billion with this method.

The analytical procedure was used to determine malachite green residues in rainbow trout eggs and larvae intermittently exposed to ^{14}C malachite green for a month. Total residues of malachite green were determined by measuring the radioactivity in the samples. Residues of malachite green accumulated in eggs over the 31-day period, even though they were treated for only 1 hour every 72 hours. After treatment, concentrations of malachite green in the tissue declined until the end of the study (day 59) because of elimination and the dilution effect of growth.

Chemicals Screened as Possible Replacements for Malachite Green

A high priority of the Service is to replace malachite green as a control agent for external protozoan parasites on cultured fish. The Fish Farming Experimental Laboratory in Stuttgart, Arkansas, screened almost 300 chemicals for lethal effect on potential protozoan parasites and for toxicity to fish. Results were compared with trials using chemicals of known effectiveness to validate the comparative tests. A high efficacy rank was based on high toxicity to the test protozoan and low toxicity to fish. Promising results were obtained for 27 chemicals, which will be further tested for usefulness in fish culture. The most effective candidate was dichlorophen, a chemical also effective in controlling fungus on channel catfish eggs. Other chemicals highly rated by this research were halazone, chloramine B, and 5-chloro-7-iodo-8-hydroxyquinoline.

Sarafloxacin as an Antibacterial

The fluorinated quinolone compound, sarafloxacin, developed by Abbott Laboratories, has been used in field trials to treat bacterial infections of cultured fishes. The great success of these trials led Abbott to

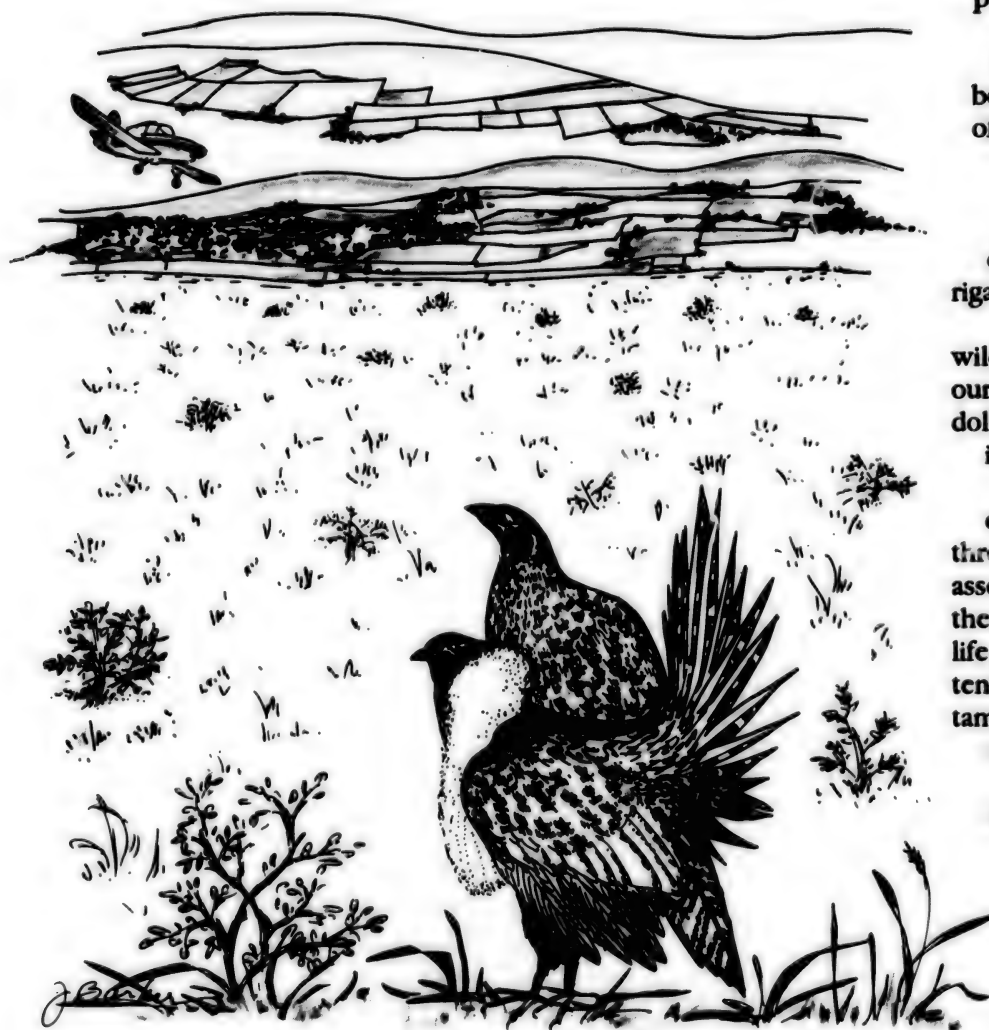
seek FDA approval to market the chemical for commercial use.

The quinolones are effective against gram-negative bacteria. One of these, oxolinic acid, was found to inhibit growth of gram-negative fish pathogens in the range of 0.0156 to 0.125 parts per million (ppm). However, because there is no sponsor in the United States willing to register oxolinic acid for use on food fish, the National Fisheries Research Center—Leetown conducted in vitro sensitivity studies on a second quinolone, sarafloxacin by using the same procedure used to test oxolinic acid. The center evaluated minimum inhibitory concentrations for sarafloxacin against several strains each of five gram-negative fish pathogens. Sarafloxacin was effective within the same range, or lower, than oxolinic acid. Development-of-resistance studies were conducted with 10 strains of *Edwardsiella ictaluri* and 7 strains of *Cytophaga columnaris*. All of the test developed resistance to sarafloxacin during and after the 30 transfers in the one-fourth minimum inhibitory concentration. The increased resistance varied from two-fold to more than 32-fold among the strains. Although there was a significant increase in resistance in most strains of the test organisms, the resistance increased 0.5 ppm, the highest test concentration in only three strains. Tissue levels of sarafloxacin in fish disease treatment routinely reach 2.0 ppm, well above the 0.5 ppm maximum

used in the study. Therefore, the compound is considered to be a good candidate for registration and use as a fish therapeutant.

In a parallel study, the National Fisheries Research Center—La Crosse evaluated the tissue distribution and elimination of sarafloxacin from three commercially and recreationally important freshwater fish species after oral administration. Use-pattern tests were run on rainbow trout and Atlantic salmon, two commercially important cold-water fishes that are cultured worldwide, and channel catfish, a warmwater species extensively and intensively cultured in the United States. The tissue distribution of sarafloxacin was similar in the two cold-water species, but it differed from that found in the channel catfish. The stomach and intestine were the principal distribution depots for sarafloxacin residues in salmon and trout even though the chemical distributed to all tissues. In channel catfish, sarafloxacin was concentrated at first in the gastrointestinal tract, but eventually was found in all tissues and organs. In all species tested, residues cleared most rapidly from the liver and the skinless fillet and least rapidly from the kidney and skin. The estimated half-life was 14.8 hours in channel catfish, 37.3 hours in Atlantic salmon, and 19.1 hours in rainbow trout. The effectiveness against bacterial pathogens and the rapid and complete loss of therapeutant residues from all three species after withdrawal from treatment suggest that sarafloxacin will be an important therapeutic tool for fish culturists in the 1990's.

Contaminants



Through research with other countries, such as the Soviet Union, it is clear that no habitat on earth, no matter how remote, is completely safe from chemical contamination. Thus, the challenge continues. In our own country, many of the thousands of new chemicals produced each year still reach our lakes, streams, and estuaries.

And in the Service itself, it has been discovered that many parts of the national wildlife refuge system include old waste disposal sites or receive water from sources contaminated by industrial wastes or agricultural irrigation drainage.

Ecosystems suitable for fish and wildlife contribute to the quality of our lives through the multibillion dollar economics of fishing, hunting, nature appreciation, tourism, and enjoyment of the outdoors. Not only do contaminants threaten these activities and their associated economics, but many of them are also harmful to fish, wildlife, and people. Frequently, the potential threat to humans from contaminants is first revealed by fishery and wildlife research.

Protecting and remedying these adverse effects of pollutants on fish and wildlife is part of the central mission of the Fish and Wildlife Service. In the 1940's, the Service addressed principally industrial pollution and in 1960's focused its attention on effects of pesticides such as DDT on fish and raptors. Today, the misuse and improper discharge or disposal of hazardous materials, seepage from old waste sites, atmospheric transport, and disturbance of contaminated sediments cause frequent and serious threats to fish and wildlife.



Research chemists at the contaminant research centers employ state-of-the-art high performance liquid chromatography to subdivide and evaluate contaminant residues in tissues at the part per billion level and at the part per trillion level in water.

Photo by D. Hardesty.

Thus, Service contaminant researchers are trying to determine and remedy the effects of acid rain, hazardous wastes, new-generation pesticides, contaminated sediments, and excess nutrients from agricultural practices.

In our early days, contaminant research focused on the use of organochlorine pesticides and their associated effects on the population levels of species. Support for this type of research was formalized in 1958 and over the next two decades researchers increased their knowledge of contaminant cycling in the

environment, lethal and sublethal effects, residue detection and interpretation, and differing species sensitivity. Service research contributed significantly to canceling the use of organochlorine pesticides in the 1970's. Today, pollution research is a rapidly changing field because of new chemical products, technological processes, advances of methodological and basic knowledge in biology and chemistry, and the varying mix of chemicals and their uses that may affect important fish and wildlife environments. In recent years, chemicals, chemical formulations, and the use patterns of

pesticides have changed dramatically, necessitating investigations of multichemical, synergistic effects relative to habitat alteration and community structure of habitats. Some contaminants of single overriding effect—such as selenium, polychlorinated biphenyls (PCB's) and dioxins—will continue to be mobilized from sediments and other deposition sites and may interact with other environmental stressors, thereby affecting a species' life cycle.

A research chemist applies the technique of automated sampling in gas chromatography to quickly evaluate residue levels in samples and identify previously unrecognized contaminants. *Photo by D. Hardesty.*

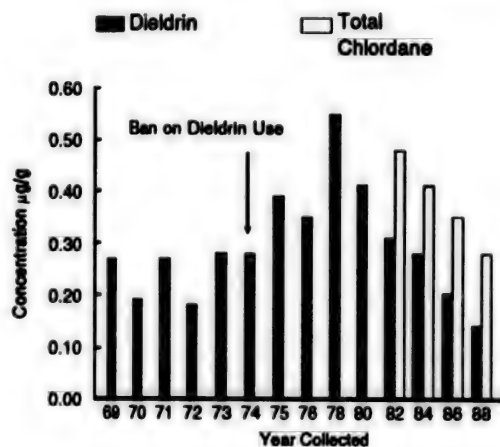
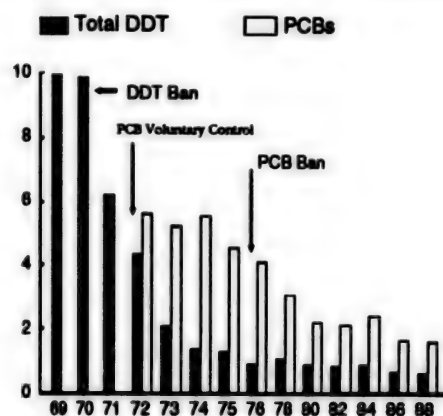


The Service's principal contaminant research centers are the National Fisheries Contaminant Research Center (fish), the Patuxent Wildlife Research Center (wildlife), and the National Fisheries Research Center—Great Lakes (Great Lakes fishes). Research is done at these principal laboratories and their field stations throughout the United States. Contaminant research on specific problems is also conducted by other Service research centers and by cooperative fish and wildlife research units at major universities.

Great Lakes: Assessing Contaminants and Their Effects

The National Fisheries Research Center—Great Lakes conducts research to assess and remedy the adverse effects of contaminants on the biotic and abiotic environment of the Great Lakes, the largest system of fresh water on earth. These lakes not only are affected by pollution from industries, cities, agricultural lands, and waste disposal sites, but because of their high surface area, they are also susceptible to atmospheric pollutants in precipitation or dust. The research emphasis at this center has been on industrial pollutants, particularly organic compounds, many of which cause reproductive failure, deformed young, or cancer in fish. The research at this center is often a joint enterprise with Canadian agencies, the U.S. Environmental Protection Agency, and State agencies under the guidance of the International Joint Commission.

Concentrations of DDT, polychlorinated biphenyls (PCB's), Dieldrin and Chlordane in bloater chubs sampled from Lake Michigan.



The Bioavailability and Persistence of Toxic Dioxin, Furan, and Biphenyl Compounds in Sediments

Polychlorinated biphenyls, furans and dioxins are complex chemical mixtures—and some components of these mixtures are among the most toxic chemicals known to humans, especially the dioxin TCDD and the structurally similar PCB's. Sediments in several areas of the Great Lakes contain high levels of PCB's, furan, and dioxin mixtures; reproductive failures of lake

trout in Lake Michigan and of Forster's terns may be linked to these toxins. Studies with laboratory fish exposures confirmed earlier reports that the most toxic dioxin and furan isomers were selectively bioconcentrated and were also the most available contaminants to fish. Data from PCB persistence studies indicated that overall concentrations of PCB's have declined in the Great Lakes, but changes in concentrations of the bioavailable toxic components are negligible. This work suggests that these toxic dioxin and furan isomers are an ongoing problem for successful restoration of the lake trout fishery in the Great Lakes.

Cancer in Fish and Carcinogens in Great Lakes Sediments

In the Great Lakes and in other freshwater and marine environments, bottom-dwelling fish that inhabit areas with polynuclear aromatic hydrocarbon (PAH)-contaminated sediments have exhibited high frequencies of cancer. The National Fisheries Contaminant Research Center joined the National Fisheries Research Center—Great Lakes in a study of cancer in the fishes of Great Lakes tributaries. Elevated frequencies of liver cancer were found in brown bullhead from the Cuyahoga and Black rivers in Ohio and in Munuscong Bay of the St. Marys River in Michigan. However, no liver cancers were found in brown bullhead from the Menominee or Fox rivers in Wisconsin, even though sediments from those systems contained elevated levels of arsenic and organochlorines (PCB's and dioxins), respectively. Accordingly, PAH's, including such human carcinogens as benzo(a)pyrene, seem to be linked to liver cancer in fish, but organochlorines do not seem to be a major cause of such tumors. The cause of liver cancers in fishes of Munuscong Bay is under further study by the Service.

Sediments from these five areas were extracted with solvents and separated into fractions with PAH and nitrogen-containing PAH. Medakas, a fish species used in carcinogenicity and mutagenicity studies, were exposed to these extracts by a multiple-pulse method. The extracts from contaminated sites were toxic to medakas during the exposures. Fin abnormalities and liver lesions were more prevalent in medakas exposed to extracts from contaminated sediment than in medakas exposed to the control (uncontaminated) extract. Tumors were also induced in medakas exposed to sediment ex-

tracts from several of the contaminated sites, but not in medakas exposed to extracts from the control site. Tumors included liver cancer, noncancerous liver tumors, and bile duct tumors. These findings support the hypothesis that chemical contaminants in sediments cause tumors in wild fishes.

Expert System Predicts Aquatic Toxicity from Contaminant Chemical Structure

The National Fisheries Research Center—Great Lakes developed an expert system (an interactive computer program) that uses the structure of an organic molecule to predict acute toxicity to four aquatic species (each species represents one of four aquatic trophic levels). The system, designed to make use of a particular quantitative structure-activity relation, is used as part of a hazard assessment of environmental chemicals and as a screening tool for the initial evaluation of contaminants detected at a site of concern. The software is capable of evaluating chemicals with ring or noncyclic skeletons, double and triple bonds, and all common functional groups (for example, acids, alcohols, amines, esters, and halides). The ring structures include cyclohexane and benzene derivatives, naphthalenes, PCB's, dioxins, dibenzofurans, PAH's, nicotine, pyrrole, and the corresponding saturated ring systems. Work is continuing to improve the system so it can be used by regulatory personnel and environmental managers to evaluate contaminants at specific sites to better protect national water resources.

Effects of Agricultural Chemicals

Today's farms are more intensively managed to reduce costs, increase production, and reduce adverse effects of chemical use. Researchers are only now beginning to document recovery of fish populations as a result of changing farm practices. However, pesticide use has increased significantly during the past decade and continues to increase. This increased pesticide use has been accompanied by a shift in types of chemicals from persistent organochlorine compounds to less persistent organophosphates, carbamates, and synthetic pyrethroid chemicals. Determining the effects of new chemicals, pesticide mixtures, aerial drift, and multiple spraying on fish and wildlife remains a primary concern of Service resource managers.

Effects of Insecticides on Nontarget Species in the Florida Keys and Everglades

Mosquito control districts typically use sprays with resmethrin, malathion, or fenthion to control larval and adult mosquitoes around populated areas in the Florida Keys. Researchers with the Florida Cooperative Fish and Wildlife Research Unit determined that nontarget Lepidopterans (butterflies) are highly sensitive to these insecticides in concentrations even lower than those being applied. The researchers also found that over a 10-year period, mosquito control in the Monroe County Mosquito Control District has reduced the number of adult butterflies along established transects within the Everglades National Park.



Patuxent Wildlife Research Center technicians hold three adult blue-winged teals found dead after an aerial application of ethyl parathion to sunflowers in North Dakota. Photo by Patuxent Wildlife Research Center.

Aerial Application of Insecticides Threatens Upland Game Birds

Scientists from the Patuxent Wildlife Research Center, Northern Prairie Wildlife Research Center, and Arrowwood National Wildlife Refuge measured spray drift from aerial application of an organophosphate insecticide. Their studies revealed that in North Dakota, insecticide deposits in wetlands were equal to or greater than deposits in sunflower fields. The volume of spray drift in wetlands was enough to cause a 35% reduction in the number of aquatic invertebrates—an important waterfowl food source on the refuge—for as many as 35 days. In response to organophosphorus insecticides applied to potato fields in Idaho, brain acetylcholinesterase of sage grouse ranged from normal to 61% inhibition, indicating pesticide poisoning. A large percentage of radio-tagged sage grouse in sprayed fields died.

Multiple Applications of Insecticide Reduces Bluegill Spawning

Researchers from the National Fisheries Contaminant Research Center demonstrated that pulsed-dosing of a pyrethroid insecticide, esfenvalerate, into experimental ponds leads to unexpected effects on bluegill reproduction. Esfenvalerate was dosed into the ponds every 2 weeks over a 12-week period, simulating actual use in the field and a worst-case exposure scenario. Analysis of bluegill young produced over the summer indicated that reproduction was successful for early and late spawners but was inhibited during the time the ponds were sprayed. Although acutely toxic to invertebrates, esfenvalerate dissipates rapidly from the water column. Zooplankton were sensitive to the chemical but their short generation time and rapid growth rates allow them to recover rapidly. However,

recovery of fish populations from multiple applications may be low.

Agricultural Irrigation Drain Water

Drainwater contaminants—including arsenic, boron, and especially selenium—are now known to be hazardous to waterfowl, shorebirds, and fishes in several arid and semi-arid areas in the western United States. Kesterson National Wildlife Refuge in California was the first documented site where irrigation drain water threatened survival and reproduction of fish and wildlife. Unfortunately, Kesterson is not an isolated incident. During the past 2 years, Service biologists from the National Fisheries Contaminant Research Center, the Patuxent Wildlife Research Center, and the California Cooperative Fishery Research Unit have expanded studies on the extent and severity of adverse effects of irrigation drainwater on fish and wildlife.

Furrow irrigation of an alfalfa field in the San Joaquin Valley, California. *Photo by M. Saihi.*



Disposal of subsurface agricultural drain water from a cotton field in the San Joaquin Valley, California. *Photo by M. Saihi.*



Field Studies in California and Nevada

Recent contaminant surveys in the San Joaquin Valley of California revealed that selenium concentrations are sometimes elevated in plants and animals in or adjacent to canals, sloughs, and ponds that receive irrigation drain water. Fish, notably mosquitofish, normally thrive in these areas, establishing large populations but also accumulating contaminants. Mosquitofish from the San Luis Drain contained up to 370 parts per million (ppm) of selenium (normal levels are about 5 ppm). Because selenium is known to impair reproduction, researchers wanted to determine if mosquitofish living in irrigation drainage waters were reproducing normally. The results of their studies indicated that the proportion of newborn fry that was born alive (mosquitofish eggs hatch inside the female and the young are born alive) was reduced by 30% in fish

from drainwater sites. The stillborn fry were developmentally premature and often still curled up in a posture similar to that in advanced stages of eyed embryos. In most cases, the yolk sac had not been absorbed and still protruded from the abdomen. The high percentage of immature, stillborn fry probably represents spontaneous abortion in near-term females, a condition that also occurs in small mammals after exposure to high levels of selenium.

Recent findings in the Tulare Lake basin in California indicate that selenium levels are elevated in areas where waterfowl and shorebirds feed. In the Tulare Lake basin, selenium concentrations were high enough to cause embryo deformities and reproductive failure similar to those observed at Kesterson National Wildlife Refuge. In 1989, embryo deformities were documented for the first time in diving ducks. Exposure of shorebirds and ducks to selenium seems to be even higher in the Tulare Lake basin than at

Kesterson perhaps because birds have little uncontaminated wetland habitat at Tulare. The frequency of overt malformations in shorebirds is less than 1 per 500 embryos at uncontaminated sites but can be as high as 50-250 per 500 embryos at contaminated sites.

Although selenium is the most damaging drainwater pollutant at the Kesterson National Wildlife Refuge in California, arsenic and boron also are potential threats. In California and Nevada, concentrations of these contaminants have been found in amounts sufficient to impair growth and survival of ducks (1600 ppm boron, 30-300 ppm arsenic). Studies of exposures of fish and invertebrates to irrigation drainage at the Stillwater National Wildlife Refuge in Nevada revealed that high salinity and several inorganic elements including arsenic, boron, lithium, and molybdenum are toxic. In addition to salinity and trace elements, the

An American avocet feeding among selenium-contaminated sediments at an evaporation pond in the Tulare River basin in California. Researchers have found that eggs of this and other waterbirds contain up to 50 times the normal concentration of selenium—levels that are often toxic to bird embryos. *Photo by Patuxent Wildlife Research Center.*



unusual ionic composition of irrigation drain water may also affect toxicity levels in organisms. These findings underscore the complex nature of irrigation drain water and the many potentially toxic constituents associated with it.

Laboratory Studies

Experimental aquatic food chains were studied to determine how much selenium must be present in water to result in bioaccumulation of potentially toxic levels in food of fishes and birds. All organisms concentrated an organic form (selenomethionine) more strongly than inorganic forms (selenate, selenite). Aquatic crustaceans (*Daphnia*) concentrated organic selenium as much as 350,000 times the concentration present in water. Of the inorganic selenium forms, algae and aquatic crustaceans accumulated selenite more strongly than selenate. These results indi-

cate that fish accumulate most selenium residues by eating contaminated food. However, the concentration factor (ratio of selenium in food to selenium present in body tissues) for fish is not large and usually ranges from 1 to 2. Major bioaccumulation in the food chain seems to be by the primary producer (algae) and primary consumer (invertebrates) pathways. Concentrations of selenium in algae and invertebrates are already hundreds—or perhaps even thousands—of times higher than in the water. After selenium has entered the food chain, fish and birds are exposed to concentrated amounts and little additional accumulation is necessary for toxic effects.

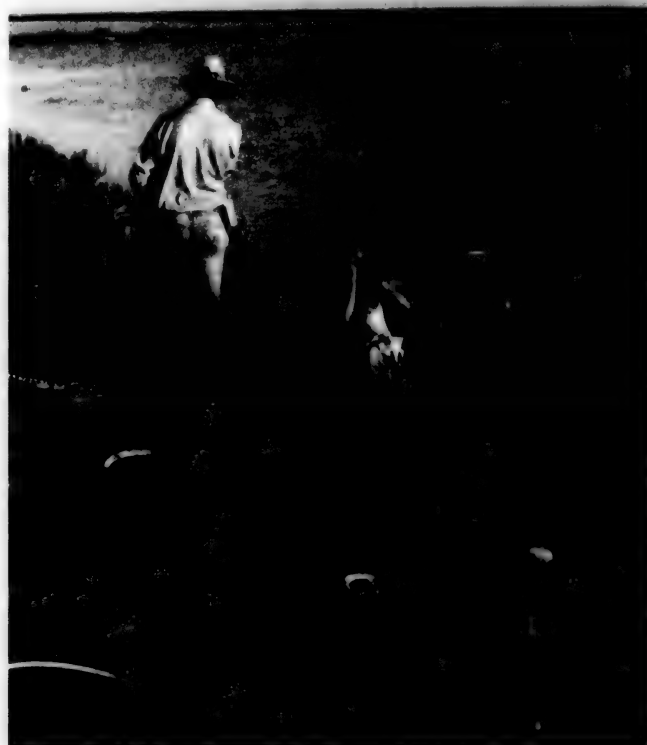
The finding that organic selenium is accumulated to a much greater extent than the inorganic forms is of particular importance in understanding the selenium cycle in nature and the potential hazard of even low waterborn concentrations. In laboratory studies, organoselen-

ium compounds contributed disproportionately to bioaccumulation of selenium and may also do so in natural aquatic habitats. Conclusions from past field studies may have erroneously interpreted waterborne bioaccumulation of selenium as benign. Although present at very low (below part per billion [ppb]) aqueous concentrations, a small fraction of the total organic selenium may be a major factor leading to the observed bioaccumulation. Establishing adequate water-quality criteria for the protection of fish and birds may hinge on comprehensive knowledge of the role of organoselenium in bioaccumulation and toxicity.

Management Implications

Unanswered questions remain, but after years of intensive field and laboratory research our knowledge of drainwater pollution has now

Biologists monitor duck eggs for live embryos at an evaporation pond in the Tulare River basin of California. At some sites, more than half of all monitored eggs failed to hatch because of high selenium exposure. Many other contaminants occur in these ponds, but so far only selenium has been found at toxic concentrations in bird eggs. *Photo by Patuxent Wildlife Research Center.*



reached the point where practical management recommendations can be made to protect fish and birds. Research has shown that the embryo (birds) and larvae (fish) are the most sensitive life stages to drain water pollution. Selenium accumulates in the food items consumed by adults and is passed on to the developing embryo in the egg. As the embryo develops, the egg yolk is absorbed and the selenium exerts its toxic effects in the form of physical malformations and death. If these early life stages can be protected from selenium poisoning, other life stages will be protected as well. Information from laboratory studies suggests that deformities and death of embryos and larvae begin when adult female fish and birds are fed a concentration of selenium, as selenomethionine, between 4 and 10 ppm on a dry-weight basis. Data from field studies

put the lower limit at about 5–6 ppm selenium. The amount of selenium that must be in the water for aquatic food organisms to accumulate this 5–6 ppm toxic level is quite small and varies depending on the chemical form of selenium present. Organic forms such as selenomethionine are accumulated to a much greater extent in aquatic food chains than are the two major inorganic forms, selenate and selenite. In locations where organoselenium is present, as little as 0.1 ppb in water may be all that is necessary to cause food chain bioaccumulation sufficient to ultimately impair reproductive success. On the other hand, 2–5 ppb of inorganic selenium in water may be necessary to produce the same food chain bioaccumulation and resultant threat to reproduction.

The key to preventing selenium toxicity is to keep levels of selenium in water below the thresholds at which food chain bioaccumulation

begins. The presence of organic and inorganic selenium, other trace elements, elevated salinity, and unusual ionic composition in drain water means there is a greater need for adequate freshwater supplies than previously believed. Adequate freshwater supplies would help dilute drain water, which may be necessary to prevent excessive bioaccumulation of selenium and also to help alleviate other toxic factors. Conductivity and hardness measurements can be used as screening tools to provide rapid field assessment of the overall quality of water entering wetlands and its potential hazard to aquatic life and waterbirds. From these results, fish and wildlife managers now have critical information on which to make decisions regarding water quality, habitat suitability, and water management alternatives.

Angler with striped bass caught in the Sacramento-San Joaquin Delta, California, near the proposed terminus of the now defunct San Luis Drain.
Photo by M. Saiki.



Industrial Mining Contaminants

Release of trace elements, organic contaminants, and other by-products from industrial mining activities continues to pose problems for fish and wildlife.

Fluoride at a Phosphate Processing Complex in Idaho

Elevated fluoride concentrations can manifest biochemical and morphological effects in fish and wildlife. Most fluoride pollution problems are caused by modern human-made sources, including phosphate rock processing. Fish and other aquatic species tend to accumulate fluoride in the skeleton and exoskeleton. Fluoride levels measured by the Patuxent Wildlife Research Center in femura of black-crowned night-herons that lived adjacent to a phosphate processing complex near Pocatello, Idaho, ranged from 540 to 1,100 ppm and significantly increased with age. Night-herons from Idaho contained some of the highest

fluoride concentrations ever reported for wild birds.

Lead at the Coeur d'Alene River, Idaho

Most of the Coeur d'Alene River system in northern Idaho has been severely affected by metal contamination from smelter and numerous mines along the South Fork. Adult and nestling ospreys were studied by Patuxent Wildlife Research Center scientists who determined that lead concentrations in the blood of osprey were relatively low in the area, but aminolevulinic acid dehydratase activity, an indicator of lead exposure, was depressed 66% in adult female ospreys and 57% in nestlings along the Coeur d'Alene River. Osprey production rates were uniformly high in all study areas. The fish-eating ospreys were not accumulating excessive concentrations of lead despite high levels in river sediment.

In contrast to ospreys, ducks, geese, and swans in the Coeur d'Alene River system have extremely high concentrations of lead in their blood and livers. Spring die-offs, involving a few dozen birds—or, as happened in 1982, hundreds—happen

every year. Most victims are tundra swans, a species that seems particularly vulnerable to lead—either from ingesting lead shot or from ingesting highly contaminated sediment and aquatic vegetation. From 1987 to 1989, 38 dead swans from the Coeur d'Alene River system were necropsied and diagnosed as having died from lead poisoning. Over the 3-year study, only 12% of the swans that died from lead poisoning had ingested lead shot (shot found in gizzards). Generally, carcasses of waterfowl that died from ingested lead shot contained lead shot at death. Researchers assume that most of the swans that died from lead poisoning ingested free lead from mining and smelting activities.

Selenium Near a Lignite-fired Power Plant in Texas

At Martin Lake, Texas, fish kills were reported from September 1978 to May 1979 when a lignite-fired power plant discharged selenium-laden ash into the 5,000-acre lake used as a cooling reservoir. Elevated concentrations of selenium

Lignite-fired power plants were a source of selenium in fish and birds at Martin Lake, Texas. *Photo by K. A. King.*



were present in restocked fish when the reservoir was sampled in 1981 and 1984. Selenium levels in Martin Lake fish were 9-21 times higher than the 1980-81 national mean (1.9 ppm dry weight) as determined by the National Contaminant Biomonitoring Program. In 1986, adult blackbirds at Martin Lake were collected by researchers from the Patuxent Wildlife Research Center before the birds' nesting season. These birds contained higher levels of selenium (33 ppm) in kidney tissue than blackbirds (7.7 ppm) from a nearby control area. Selenium in Martin Lake blackbird eggs averaged 11 ppm compared with 2.4 ppm in control eggs; the selenium seemed to impair reproduction. The proportion of hatched blackbird eggs at the power plant reservoir (26%) was less than half of the control (56%).

Heavy Metals from a Zinc Smelter near Palmerton, Pennsylvania

Studies conducted by researchers from the Pennsylvania Cooperative Fish and Wildlife Research Unit demonstrated that terrestrial ecosystems within 5 miles of zinc smelters have been adversely affected and vertebrate species in those areas have been reduced or eliminated. Operation of zinc smelters at Palmerton, Pennsylvania, from 1889 to 1980 resulted in large depositions of heavy metals in the surrounding environment. In general, concentrations of cadmium, copper, lead, and zinc in stream sediments, aquatic insects, and fish are highest near the smelters and decrease with increasing distance from the source. However, no consistent spatial trends in insect communities, fish communities, fish growth, or trout reproduction exist. One site that appeared abnormal was Aquashicola Creek, about 0.5 miles downstream of the smelter waste

pile. Leachates from this waste disposal area seem to provide a continuous supply of heavy metals to the stream. In this creek, downstream insect communities are depressed and fish have elevated levels of heavy metals. Levels of cadmium in kidneys of white-footed mice were four to five times higher, and bone tissues had significantly higher levels of lead and zinc at sites near the smelters than in sites more than 8 miles upwind or downwind of the smelters.

Mercury and PCB's in River Otters

Recent studies of contaminant levels in river otters from the United States and Canada suggest that the otter may be a useful species for identifying watersheds with high levels of environmental contamination. The Massachusetts Cooperative Fish and Wildlife Research Unit examined livers of trapper-harvested river otters for mercury and PCB residues and found a meaningful correlation between residues in fish and in otters. These results suggested that river otters can be used for assessing general background mercury and PCB-contaminant levels by watershed to rank monitoring needs and to justify more intensive contaminant monitoring.

Contaminated Sediment: Technological Development

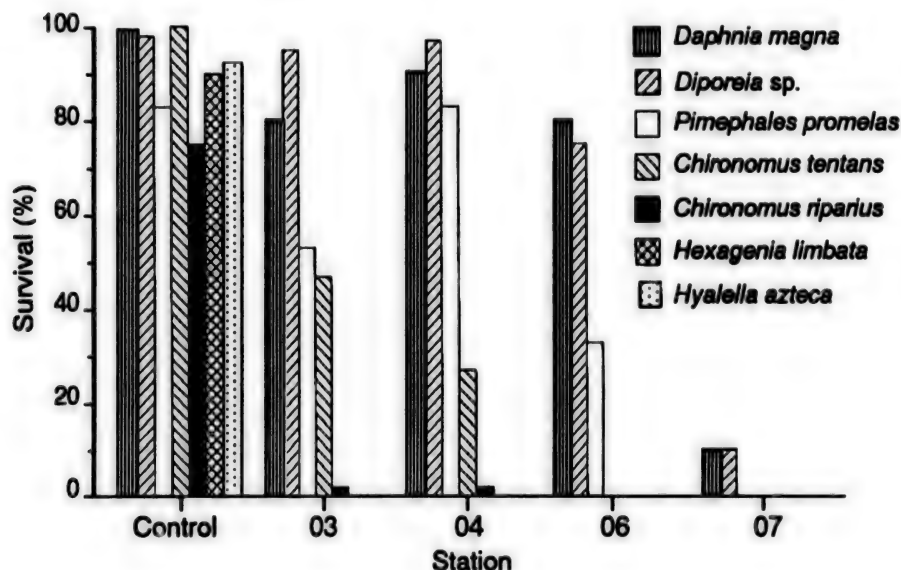
Biological Assessment of Contaminated Sediment

Although discharges of contaminants into the nation's surface water have declined substantially over the past several decades, problems with

contamination persist in many historically contaminated areas. Because contaminants released into surface water may become associated with the bottom sediments, concentrations of contaminants in sediment are often much higher than in sediments in the overlying surface water. Contaminants known to accumulate in sediment include petroleum hydrocarbons; polycyclic aromatic compounds (PAC's) such as PCB's, dioxins and furans; pesticides; herbicides; and heavy metals. Over time, these contaminants may be slowly released from the sediment into the overlying water. Contaminants released from the sediment can be directly toxic to aquatic life or can be a source of contaminants for bioaccumulation in the food chain.

For the past several years, the National Fisheries Contaminant Research Center has explored methods to determine toxicity to aquatic organisms from contaminants in sediment. Partial life-cycle, sediment-testing methods have been developed for the freshwater crustacean *Hyaella azteca* and the midge, *Chironomus riparius*. These animals live in direct contact with sediment, are sensitive to many contaminants, have short life cycles, can be cultured in the laboratory, and are ecologically important. Effects of contaminated sediment on the survival, growth, and reproduction of these test animals are monitored after several weeks of exposure in the laboratory.

These methods were used to determine the potential toxicity of contaminated sediments from several locations including the Great Lakes, the upper Mississippi River, and the Trinity River in Texas. Sediments from these areas contain parts per million concentrations of several contaminants, including petroleum hydrocarbons, pesticides, PAC's, PCB's, herbicides, or heavy metals. In some tests, survival of



Survival of aquatic animals exposed for 7 to 28 days to contaminated sediments originating in Indiana Harbor, Indiana. Elevated levels of contaminants in the sediment included petroleum hydrocarbons, polycyclic aromatic compounds, and heavy metals.

animals may be reduced after short-term (7 day) and long-term (28 day) exposure to contaminated sediment. In addition, sublethal effects on the growth and reproductive development have been observed. No single aquatic species is the most sensitive to all contaminants; therefore, several species were tested.

Sediment toxicity tests with complex mixtures of contaminants are also useful for evaluating the extent of needed cleanup at contaminated sites. Data from sediment toxicity tests are being used to derive Sediment Quality Triad (SQT) and Apparent Effect Threshold (AET) values for freshwater sediments. The SQT and AET integrate data from laboratory exposures, benthic community structure, and chemical and physical analyses—providing evidence of pollution-induced degradation in aquatic communities. The SQT and AET values provide a direct assessment of sediment quality; these values can be used in making decisions for further chemical or biological testing of sediments.

Acid Precipitation

Any form of precipitation—rain, fog, snow, or sleet—with a pH of less than 5.6 is considered acidic. Acids in acidic precipitation are primarily sulfuric and nitric acids that result from sulfur and nitrogen oxides in emissions. The major sources of atmospheric sulfur are the industrial uses of high-sulfur coal and metal smelting, but volcanic eruptions, sea spray, and hydrogen sulfide generation in bogs and swamps also contribute. Natural sources of acid precipitation—such as the oxidation and photooxidation of a variety of nitrogenous compounds—contribute a major portion of the nitrogen in acid precipitation, but combustion of natural gas and automobile emissions also add significant portions, especially in urban areas. Hydrochloric acid contributes a small portion of the acid in acid precipitation and results primarily from industrial activities.

Weather patterns may transport acid-producing pollutants to remote areas far from their sources. Aquatic organisms that inhabit these waters

may be affected by the acidity alone, or by acidity in combination with toxic elements such as aluminum that can be leached from watershed soils and aquatic substrates by acidic precipitation. Many resources of concern to the Service, including a variety of endangered or threatened species, may be threatened by acid precipitation.

Effects of Acid Precipitation on Aquatic Resources

Fish

During major rainfall or spring snowmelt, surface waters may experience severe pH depressions, and concentrations of metals such as aluminum may reach toxic levels. A field study conducted by the Pennsylvania Cooperative Fish and Wildlife Research Unit documented the frequency, duration, and severity of episodic pH depressions in five headwater streams. Several water quality variables were monitored continuously, and water samples were taken during storms to document changes in stream water

quality. Wild brook trout and sculpins were held in cages in the streams for 20 days during spring to determine the toxicity of stream water. The number of fish deaths increased with increased concentrations of dissolved aluminum. The fish moved more during the acidic episodes, and generally inhabited stream reaches with relatively higher pH and lower aluminum concentrations than the main flow of the stream. Alkaline groundwater seeps, springs, and spring-fed tributaries provided instream refuges for the fish. Few brook trout and no sculpins were in the stream when aluminum concentrations were greatest during storms. Brook trout were abundant in the other streams even though two of the streams had high dissolved aluminum concentrations (400 ppb) during storms. Sculpins were only in the two streams with the lowest aluminum concentrations (less than 100 ppb). These results indicate that fish will seek instream refuges that may lessen the effects of such aluminum episodes; populations of wild fish may be reduced or eliminated in waters that experience episodic pH reductions and increases in dissolved aluminum concentrations.

Effects of episodic pH depressions and elevated aluminum concentrations on fish were further assessed in controlled laboratory studies at the National Fisheries Contaminant Research Center. Brook trout were exposed to four 48-hour acidic pulses of pH 4.0, 4.5, 5.3, 6.0, and 6.5 alone and with 300 ppb aluminum, and their survival, growth, and whole-body concentrations of calcium, magnesium, potassium, and sodium ions were monitored. After each pH and pH/aluminum pulse, the fish were allowed to recover for 120 hours in soft water at pH 7.2. Trout exposed to pH 4.0 pulses were significantly smaller than those exposed to pulses of pH 4.5, 5.3, 6.0, and 6.5.

In general, trout growth was most severely affected by pulse exposure to pH's below 6 with aluminum. Brook trout mortality was significantly increased in the pH 4.0 pulses but not in the other pH pulses. The most severe mortality occurred in pulses of pH 5.3 and 6.0 with aluminum. Both the pH pulses alone and those with aluminum reduced whole-body calcium, magnesium, potassium, and sodium in trout; the most severe reductions occurred in pH 4.0, 5.3, and 6.0 pulses with aluminum. The results of these controlled laboratory studies support the field observations that cyclic pH depressions with concurrent increases in dissolved aluminum can cause decreased survival and adverse effects on the overall health of natural fish populations.

Amphibians

Many amphibian species may be vulnerable to acid precipitation because amphibians breed in temporary ponds that are dependent on rainfall or snowmelt. The National Fisheries Research Center—Leetown conducted studies of effects of precipitation, water quality, and acid precipitation on amphibian species at Cape Romain National Wildlife Refuge in coastal South Carolina. The ephemeral ponds on Bulls Island, the largest island of the refuge, serve as breeding areas for seven species of anurans: the green tree frog, spring peeper, squirrel tree frog, southern leopard frog, oak toad, southern toad, and the bullfrog. The critical pH for the spring peeper is 4.2; bullfrog, 4.3; and southern leopard frog, 4.1. The pH's of the ephemeral ponds that are monitored do not now reach these critical pH levels, indicating that these three species are not presently at danger in that region. Critical pH's are being determined for the other anurans that inhabit Bulls Island.

Mitigation

Stringent guidelines for urban and industrial emissions would help immensely in solving the acid precipitation problem. However, the adoption and enforcement of such guidelines will probably be impeded by economic and political restraints. Meanwhile, better understanding of the environmental impacts of acid precipitation and mitigative strategies will help protect and conserve natural resources. In this light, the National Fishery Research Center—Leetown is evaluating the ecological aspects of neutralizing lake and stream systems with lime (calcium carbonate). Lime applied to Whetstone Brook in central Massachusetts, Laurel Branch in Tennessee, and Dogway Fork in West Virginia improved the water quality and status of the biota. In addition, Thrush Lake in Minnesota was treated with a single dose of 4.5 tons of lime. There, the neutralizing capacity, dissolved inorganic carbon, pH, specific conductance, calcium, and magnesium were significantly improved over pretreatment conditions in the lake. Other significant improvements, including declines in chloride, sulfate, total inorganic aluminum, and increases in nitrate-nitrogen, ammonia-nitrogen, sodium, potassium, total phosphorus, and nitrogen, were also observed. The macrophyte, baby pondweed, and the populations of brook trout, fathead minnows, and pearl dace increased over pretreatment levels. After the addition, the loss rates of the lime were low and dependent on seasonal outflow patterns and in-lake mixing processes. With few exceptions, liming has been demonstrated as an effective tool in treating acidic or acid-stressed lakes and streams.

Coastal Wetlands

Contamination of the world's coastal waters increasingly causes disease and pathology in marine and estuarine organisms. Estuaries are vital to the survival and reproduction of fish, shellfish, and waterfowl. However, more than one-half of the nation's people live and work in coastal areas even though these areas make up less than 10% of the United States landmass. Estuaries, already stressed by agricultural and industrial runoff, will be further stressed by the predicted increase in coastal urbanization. Many contaminants are discharged directly into estuaries or are transported there by rivers. To assess the degree and extent of contamination of coastal estuaries and to provide useful information for regulatory and decision-making authorities, Ser-

vice researchers evaluated the effects of contaminants on coastal fish and wildlife.

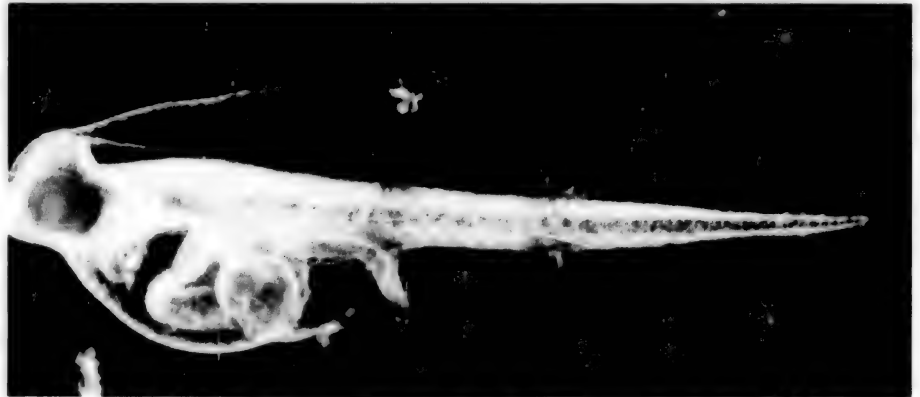
Field Toxicity Assessment Methods

The National Fisheries Contaminant Research Center's Field Research Station at Corpus Christi, Texas, evaluated several species of benthic infaunal amphipods for use in conducting toxicity tests with estuarine sediments. The amphipod species that are now routinely used in marine sediment toxicity testing are not amenable to laboratory culturing and must be collected just before testing. Two species, the haustoriid *Lepidactylus triarticulatus* and the corophid *Granditellerella japonica* were successfully cultured in the laboratory and are

being evaluated for use in studies of coastal sediment quality.

In addition to whole sediment toxicity, sediment pore water and sea-surface microlayer samples are also being tested. Positively buoyant fish eggs, larvae, and planktonic species may be in continual contact with the sea-surface microlayer. Many organic compounds and trace metals tend to migrate to and accumulate in the sea-surface microlayer to levels toxic to sensitive marine organisms. Tests with sea urchins, fish embryos, and fish larvae were conducted with morphological development and genotoxic endpoints. A life-cycle test with a polychaete and chronic tests with a benthic ostracod were also used. The results of these tests indicate that these species are suitable for testing with sediment pore water and microlayer samples. Sediment pore water tests seem to be more

Newly hatched red drum larvae were exposed to sediment pore water from an uncontaminated site. Photo by S. Carr.



Newly hatched red drum larvae were exposed to sediment pore water from an oil field brine discharge site. The exposed red drum larvae exhibit characteristic abnormalities, including scoliosis; undifferentiated internal organs, median fins, myomeres, and cephalic region (especially the eyes); and edema of the body cavity. Photo by S. Carr.





Waterbirds in Galveston Bay, Texas, against a backdrop of coastal industrial development. Photo by K. A. King.

sensitive than whole sediment tests, which are now commonly employed. Additionally, sediment pore water tests offer several other advantages; for example, samples can be stored frozen for extended periods without any toxicity change. Studies to assess sediment quality were conducted in Mobile Bay, and more investigations are now underway in Corpus Christi, Nueces, Matagorda, and Galveston bays.

Contaminant Studies in the Pacific Northwest

Aluminum, cadmium, DDE, lead, mercury, PCB's, and selenium were found in some of the surf scoter population in the Pacific Northwest. Researchers are uncertain if contaminant uptake occurred on the breeding or wintering grounds of these birds. Arsenic and selenium concentrations in surf scoters were less at Commencement Bay, Washington, than in San Francisco Bay, but selenium concentrations were well above levels in birds at Kesterson Wildlife Refuge. At Commencement Bay, cadmium was 50 times

higher in surf scoter than in western grebes. Diet and separate breeding areas are two probable reasons for the contaminant differences in the two species. Mercury concentrations in Pacific Northwest scoters and in north San Francisco Bay scoters were similar. Puget Sound in the Pacific Northwest and San Francisco Bay scoters contained similar concentrations of cadmium, but scoters at Alsea Bay, Oregon, contained higher concentrations. Cadmium was negatively correlated with both liver and body weights of Pacific Northwest scoters.

National Contaminant Biomonitoring Program

The National Contaminant Biomonitoring Program has documented declining concentrations of DDT, total PCB's, and other persistent contaminants in the environment, and is now developing new

monitoring strategies to recognize and evaluate recent questions posed by complex mixtures, short-lived pesticides, and new and previously unrecognized chemicals.

Among the mixtures being evaluated, PCB's comprise 209 chemically similar compounds of highly varying toxicity and persistence. To understand how the composition of such mixtures change with declines in overall concentration, residues in samples of lake trout and lake whitefish collected during 1979-86 from Lakes Superior, Michigan, and Huron and kept by the National Contaminant Biomonitoring Program were reanalyzed by isomer-specific gas chromatographic methods. Samples collected in 1983 from Lake Siskiwit, a landlocked lake on Isle Royale in Lake Superior, were also analyzed. Multivariate statistical analysis revealed compositional similarity between Lakes Superior and Siskiwit and Lakes Huron and Michigan. The samples from the upper lakes (Superior and Siskiwit) differed compositionally from those of the lower lakes (Michigan and Huron), suggesting that discharge of PCB's into Lake Superior are atmospheric whereas

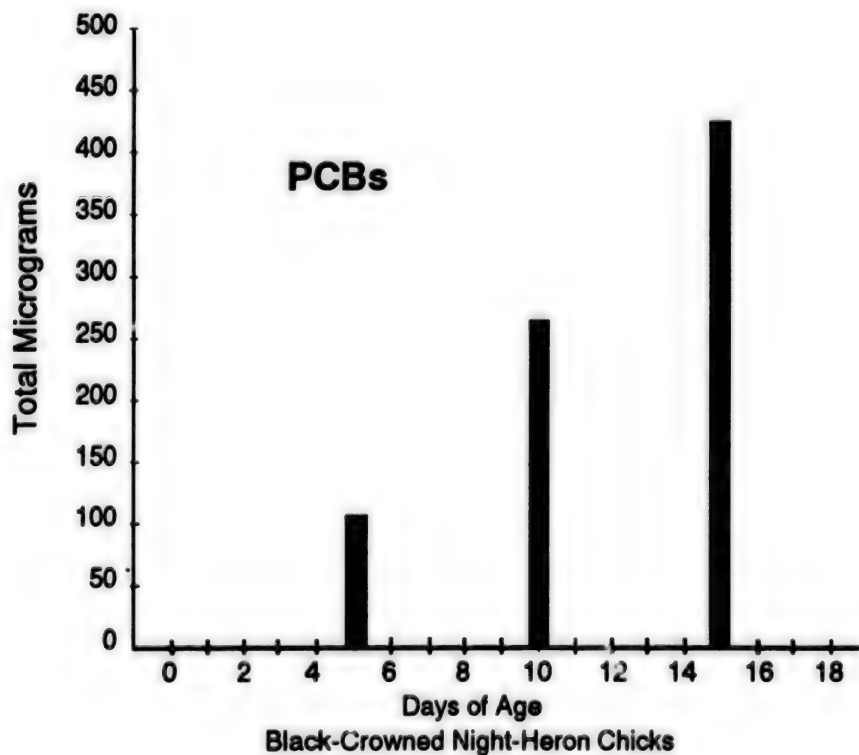
Black-crowned night-heron adults may have potential as a bioindicator for the National Contaminant Biomonitoring Program.
Photo by K. A. King.



Lakes Michigan and Huron receive a greater proportion of pollutants in runoff from watersheds. Moreover, the most recent samples (1984) from

the lower lakes resembled samples from the upper lakes more than earlier samples (1977) and are further

evidence of reduced discharge from the watersheds.

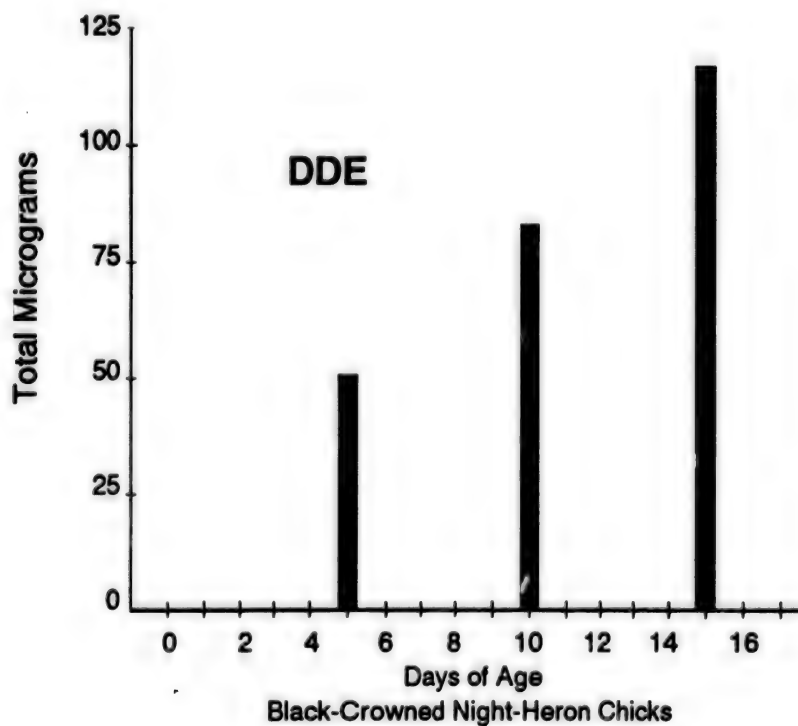


PCB accumulation in black-crowned night-heron chicks in San Francisco Bay, California.



Black-crowned night-heron hatchling and egg are being evaluated as potential bioindicators of contaminant presence. *Photo by T. Coster.*

DDE accumulation in black-crowned night-heron chicks in San Francisco Bay, California.



Searches for previously unrecognized contaminants revealed the presence of several compounds not previously encountered in fish samples from the National Contaminant Biomonitoring Program. Dimethyl diphenylmethanes, the major constituents of a dye solvent mixture that replaced PCB's in the manufacture of carbonless copy paper, were detected in fish from the Hudson River in New York, the Raritan River in New Jersey, and the Ohio River in Ohio. The compounds make up 3% of the weight of the paper and are released into the aquatic environment by paper mills that manufacture or recycle carbonless copy paper.

Another novel group of compounds—brominated diphenylethers—are commercial flame retardants, which are routinely added to carpets, textiles, and plastics in amounts as great as 20% by weight. Upon combustion, brominated diphenylethers can be converted to polybrominated dibenzofurans, which are structurally similar to their chlorinated analogs, the polychlorinated dibenzofurans. Brominated diphenylethers were found in fish from the Ohio River and the Penobscot River in Maine.

A synthetic musk compound for fragrances, trinitro-*t*-butyl-xylene, was found in fish from the Raritan River. This compound has been reported previously in fish from the United States and Japan. In contrast, previously unreported *m*, *p*-isomers of DDT (and its metabolites, *m*, *p*-DDD and -DDE) were tentatively identified in fish from the Ohio River. These isomers, which are impurities in technical DDT, suggest a production or formulation origin.

Fish-eating, colonial-nesting waterbirds are being evaluated as bioindicators for contaminants in wetlands. In California, DDE concentrations in 16% of the eggs of black-crowned night-herons from nests

around San Francisco Bay, the San Joaquin Valley, and the Salton Sea were higher (geometric mean of 8 ppm) than concentrations previously identified as the cause for reduced reproductive success in this species. In another study, DDE and PCB accumulations were measured in 5 to 15-day-old night-herons and snowy egrets from Narragansett Bay, Rhode Island; the Houston Ship Channel, Texas; and San Francisco Bay. Because night-heron and egret chicks receive food from nearby sites, contaminants in their tissues reflect local conditions. Residue concentrations in chicks increased linearly with time at all three locations. These findings support the suitability of these species as indicators of contaminants in water bodies.

Bioassessment Technologies

Improved bioassessment technologies are able to detect contaminants and evaluate their effects at all levels of biological organization. These new techniques are expected to meet the increasingly urgent demands by the Service and many other agencies for comprehensive assessment of contaminants on fish and wildlife habitat.

Biochemical Indicators

Scientists at the National Fisheries Contaminant Research Center are investigating the suitability of aminolevulinic acid dehydrase (ALA-D) and metallothionein as biochemical indicators of metals. ALA-D is an enzyme involved in the synthesis of hemoglobin and other heme-containing proteins. Metallothionein is a protein of low molecular weight with a high affinity for certain metals. ALA-D activity in fish is highly correlated with levels of water contamination by metals. Calibration of the

ALA-D response over a graded range of contamination is in progress. Evaluations of metallothionein levels in fish from several sites will be completed soon.

At the National Wildlife Health Research Center, scientists are conducting studies in the field and laboratory to determine effects of metals on immunity to diseases by waterfowl. Enhanced susceptibility to disease from lead was implied by subtle but significant changes in properties of blood, spleen weights, and the ability of spleens to produce antibodies in male mallards that had been exposed to lead through natural ingestion of lead shot in the field or through feeding of lead shot in the laboratory.

Biochemical indicators of metabolic changes from exposure to contaminants are also under investigation by scientists at the Patuxent Wildlife Research Center. A battery of assays is used to distinguish between different cytochromes P-450. This group of enzymes is known to metabolize and be affected by a variety of contaminants. Laboratory studies have demonstrated detectable changes in the metabolic activity of hepatic P-450 in mallards after exposure to contaminants. Field studies revealed that a three-fold increase in activity of one form of P-450 (arylhydrocarbon hydroxylase) in Forster's tern hatchlings is associated with elevated concentrations of PCB's and dioxins in the Great Lakes.

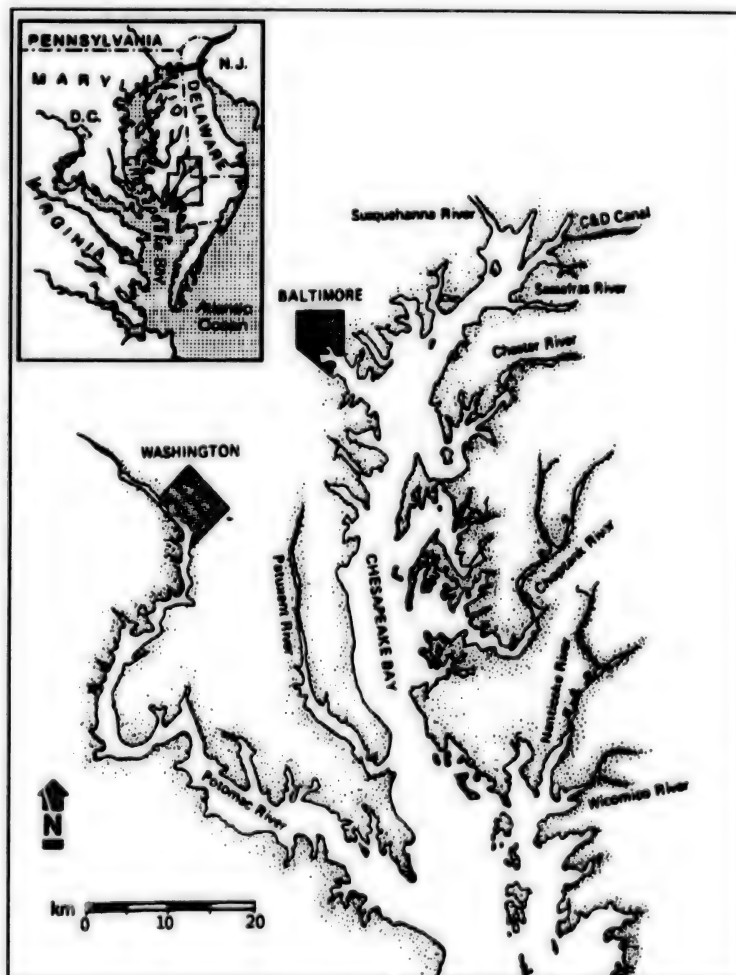
Organism-level Indicators

For several years, researchers at the National Fisheries Contaminant Research Center determined the presence of contaminants in municipal, industrial, and agricultural runoff by testing fish and aquatic invertebrates for toxicity. The same tests, which can be applied in the field, are now used extensively in assessing toxicity of water bodies from complex mixtures of contaminants.



On-site toxicity tests have provided information on contaminant concentrations and toxicity of the surface microlayer in several Chesapeake Bay tributaries. Photo by A. Livingstone.

General location of more than 80 on-site toxicity assessments conducted during 1989 and 1990 in critical striped bass spawning areas in Chesapeake Bay.



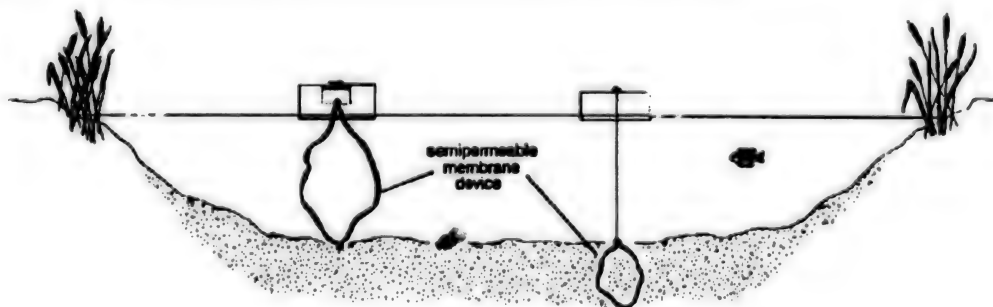
For example, in 1989 and 1990, these tests demonstrated that survival of striped bass larvae was 50–70% lower in two rivers in Maryland than in two rivers in Virginia. The same tests also suggested that the poor survival of bass in Maryland was probably caused by the presence of inorganic contaminants such as cadmium, chromium, lead, nickel, and selenium, which were not detected in the Virginia streams. These assessments verified the importance of good water quality and the detrimental effects of contaminants on critical spawning habitats of striped bass. Moreover, the assessments confirmed that contaminants inhibit recovery of striped bass and other anadromous species in Chesapeake Bay.

Bioavailability Indicator

Knowledge of types, amounts, and bioavailability of contaminants in aquatic habitats through time is necessary to assess their adverse effects on fish and wildlife. However, chemical exposure may be transient, as happens in chemical spills or pesticide application, or it may occur at levels that are too low for detection by available analytical techniques. Researchers at the National Fisheries Contaminant Research Center are developing a new technique for water sampling that mimics concentration of contaminants by water organisms. The

sampling device consists of flat polyethylene tubing that encloses a thin film of fish lipid. The polyethylene membrane allows only bioavailable contaminants to concentrate in the enclosed lipid. Parts-per-trillion concentrations of a tetrachlorobiphenyl (TCB) in water were concentrated a millionfold to parts-per-million levels in the sampler. This closely corresponds to concentrations in lipids of fish that were exposed to TCB under similar conditions. This technology seems to be a useful new tool for determining the presence and time-integrated concentrations of bio-available contaminants in water.

Thin films of fish lipid inside semipermeable "lay flat" tubes sample contaminants in water and sediment. This technique mimics the capacity of aquatic organisms to concentrate pollutants.



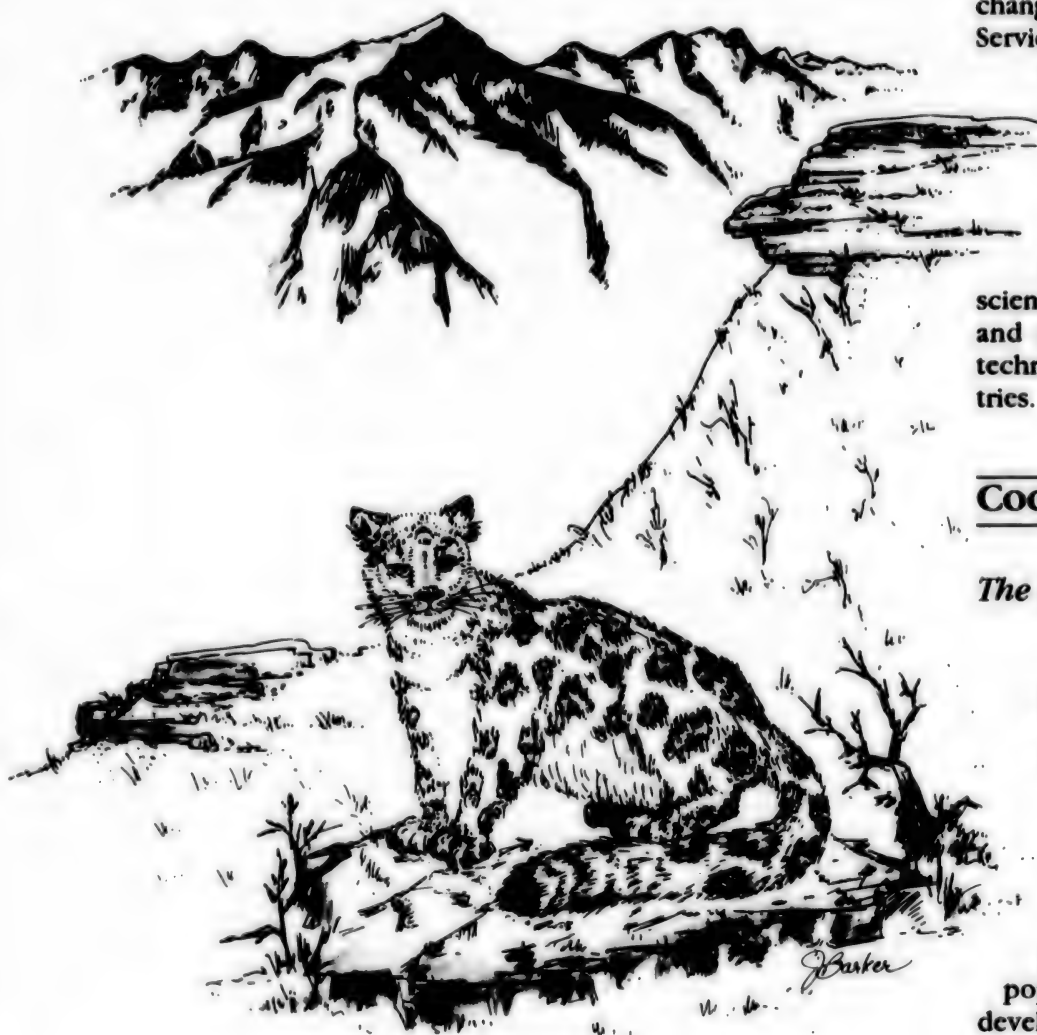
International Activities

Many researchers of the U.S. Fish and Wildlife Service are national and international authorities in their fields. Consequently, their expertise is frequently sought by foreign governments to assist in developing special programs, evaluate the effectiveness of existing efforts, or participate in scientific exchanges. During the past 2 years, Service scientists conducted numerous international cooperative research projects, assisted in the formulation of international policies concerning fish and wildlife resources, provided research and training opportunities for scientists visiting the United States, and contributed to training and technical assistance in many countries.

Cooperative Research

The Soviet Union

Cooperative research between the Alaska Fish and Wildlife Research Center and the Soviet Academy of Sciences and Ministries of Fisheries and Agriculture has confirmed the extent to which the United States and Soviet Union share polar bear and Pacific walrus populations. These researchers developed and standardized techniques for future assessment of the status and health of these animals, and began exchanging satellite imagery to relate habitat use and development on an international scale. In addition, the Alaska Center began cooperative research with the Soviets to develop techniques to in-



crease precision and accuracy in estimating Pacific walrus populations. This research has resulted in specific recommendations for walrus management that biologists in both countries can use. Satellite telemetry shows promise for helping us understand the overall scope of walrus movements and to define their population boundaries. A cooperative research program has also been established with the Soviets to develop compatible methods of exchanging and analyzing remotely sensed data for other wildlife in arctic regions. The status of Pacific black brant (a kind of goose) in the Soviet Union and the United States, is the focus of research between the Alaska Center and the Soviet Academy of Sciences, Institute of Evolutionary Morphology and Ecology, and Wrangel Island Reserve in the Soviet Union. Researchers hope to measure brant populations on Wrangel Island and adjacent mainland habitats and to evaluate the fall and winter distribution of brant that nest and molt on Wrangel Island and Russia's Chukotskiy Peninsula.

In 1988, the National Fisheries Contaminant Research Center began collaborative research with scientists from the Soviet Academy of Sciences' Institute of Biology of Inland Waters on the effects of atmospheric acidification of lakes and streams and mobilization of metals on aquatic organisms. In 1989, scientists from the center visited the Soviet Institute to survey a series of Soviet lakes for atmospheric acidification. In addition, researchers developed mesocosm methodologies to evaluate the effects of new insecticides on the structure of aquatic communities. (Mesocosms are small ponds or enclosures in larger water bodies and are used to compare assessments based on laboratory data with those based on measures of

stress in aquatic ecosystems.) These studies have led to the first reports of atmospheric acidification of some Soviet lakes and to methods for identifying histopathological individuals in fish populations exposed to acid conditions and heavy metals. In 1990, scientists from the institute and the center began studies on the effects of pollution, impoundment, channelization, flood control, power generation, water withdrawal, and channel dredging on the aquatic resources of the Volga, Mississippi, and Missouri rivers.

In another project, scientists from the National Wildlife Health Research Center and Patuxent Wildlife Research Center assisted Soviet scientists with research on cranes in the Soviet Union. Researchers performed laparoscopic examinations to determine the sex of rare cranes at Okskiy State Nature Preserve and made physical examinations of eight species of cranes at the preserve and the Moscow Zoo. Information exchange and scientific discussion between the researchers focused on all aspects of crane captive breeding methods and management. Recommendations and proposals were developed to promote the conservation of cranes and other rare bird species under the U.S.-U.S.S.R. Environmental Agreement.

In cooperative venture with the Soviet Union (the U.S.-U.S.S.R. Joint Agreement for Protection of Arid Ecosystems), researchers from the National Ecology Research Center, Alaska Fish and Wildlife Research Center, National Center for Atmospheric Research, and the National Academy of Sciences visited the Desert Research Institute in Russia to define areas of cooperation. The Aral Sea and Colorado River basins will be studied comparatively. Researchers will focus on the human-caused ecological problems that result from major water resource development

of arid-land rivers. A bilateral working session will identify similarities between the two arid river systems and identify the most important issues for specific investigation. Scientists will work in pairs, one from the United States and one from the Soviet Union.

Mexico and Puerto Rico

In cooperation with Mexican biologists, National Ecology Research Center personnel gathered ecological data on 14 species of migratory birds that winter in the undisturbed upland dry forests, regrowth forests, and pastures of Quintana Roo, Mexico. Scientists tried to determine which species of North American migrants are most dependent on forests as winter habitat. During winter, overall populations of all forest migrants declined, especially in cleared and second-growth habitats. Forest birds found in second-growth and other disturbed habitats generally were found in areas with small patches of trees. This suggests that the carrying capacity of agricultural areas for wintering birds could be increased if small patches of tree cover or hedgerows are maintained. In a study complementing the work in Mexico, members of the Missouri Cooperative Fish and Wildlife Research Unit and the National Ecology Research Center have expanded a program for monitoring warbler populations wintering in the Guanica Forest, Puerto Rico. Recent results give evidence that warbler populations continue to decline and that some species have highly skewed sex ratios. The 18-year program has provided one of the few long-term data sets available for identifying trends in winter warbler populations.



Young woman and three children in Ladakh, the highest inhabited territory in India. The rock walls are used as pens for domestic stock; snow leopards sometimes enter these pens to kill goats or sheep. *Photo by J. L. Fox.*

India

The Montana Cooperative Wildlife Research Unit, in cooperation with the Wildlife Institute of India and the International Snow Leopard

Trust, recently completed a survey of the snow leopard and its major prey. Blue sheep and ibex are the most common ungulate prey of the snow leopard. The primary cause of death for the leopard appears to be humans killing the animals in retali-

ation for livestock predation. As a result of this project, the State of Jammu and Kashmir has begun a snow leopard recovery program by creating or expanding three new national parks in the northern part of the state.

Scientist from National Wildlife Health Research Center—Madison assisting with implantation of radio in an otter at Wildlife Institute of India—Delhi Zoo.



International Cooperation

A biologist from the National Ecology Research Center acted as a consultant for several other government agencies on international aspects of marine mammal protection and conservation. These activities included working with the Departments of Commerce and State on the International Whaling Commission and the Driftnet Impact Monitoring, Assessment, and Control Act (Driftnet Act). (The Driftnet Act was enacted because of concern over the effect of the driftnet fisheries of Japan, Taiwan, and the Republic of Korea on U.S. salmon stocks, marine mammals, and marine birds of the North Pacific Ocean.) This researcher served as a scientific advisor to the U.S. commissioner to the International Whaling Commission, participated in all sessions of the commission meeting, and was chairman of the Scientific Committee of the commission, which has representatives from 41 countries. Because of this researcher's long-standing work with the Japanese on marine resource issues, the scientist was invited to be a member of the U.S. negotiating team. Additionally, he participated in two negotiation sessions in Tokyo that resulted in an observer program on Japanese vessels operating in the area of concern.

The Patuxent Wildlife Research Center and the National Wetlands Research Center participated in several activities with the Joint U.S.-U.S.S.R. Oceanographic Program to monitor the environmental health of the Bering Sea and Central Pacific Ocean. These activities include joint cruise planning and scheduling, exchange of cruise data, and joint preparation of a monograph based on the 1988 cruise. The monitoring methods used included planktonic and benthic biological indicators

and sampling for selected chemical constituents in the waters.

Training and Technical Assistance

Cooperative Research Units

At the Montana Cooperative Wildlife Research Unit, American graduate students are studying musk deer and wild yak in China and dorcas gazelles in Morocco. Likewise, Montana Cooperative Research Unit graduate students from other countries are studying barking deer and wildlife management planning in Taiwan, blue sheep in China, and ring-necked pheasants in Montana. These international students are also studying the use and training of uneducated field personnel in wildlife departments in Southern Asia, game management planning in Pakistan, and white-tailed deer in Virginia.

As part of a cooperative venture between the Service and the Canadian Wildlife Service, students from Cooperative Fish and Wildlife Research units in Iowa, Montana, and South Dakota have traveled to Canada annually for 16 years to put bands on ducks in August. In the fall, these students conduct analyses on the band-return data. The arrangement provides training for students and assists in banding of waterfowl for monitoring and research projects.

National Wetlands Research Center

The National Wetlands Research Center provided an invited instructor to a United Nations-sponsored training workshop in Malawi. The instructor lectured on ways to increase production of fuel wood on existing farmlands in Swaziland,

Africa, and on survey methods for fuel wood supplies. The event was attended by foresters from 14 African countries.

In the 1987-88 Biennial Report, the National Wetlands Research Center stated that a delegation of four Chinese scientists toured the United States observing Federal, State, and private efforts to preserve the American alligator. These scientists wanted to learn methods to preserve their own seriously threatened Chinese alligators. The National Wetlands Research Center reports that since then, some of the group have successfully bred a second generation of Chinese alligators in captivity at the Anhui Alligator Breeding and Research Center.

National Wildlife Health Research Center and the National Ecology Research Center

The National Wildlife Health Research Center provided several months of training in wildlife pathology and disease control and management for two veterinarians from Spain. These veterinarians will pursue a research project on causes of bird mortality at the Donana National Park in southern Spain, a major wetland included in the Ramsar Convention on wetlands conservation because of its biological importance. Examples of more transient involvement with foreign scientists pursuing various aspects of wildlife health problems include site visits to the center by veterinarians for the Zoological Society of London and scientists from the United Kingdom, Venezuela, Taiwan, the Gorgas Institute and Summit Wildlife Center in Panama, and the University of Alberta and the Alberta Department of Lands and Forests in Canada. Chinese researchers asked permission to



Graduate student of the Wildlife Institute of India, joint collaborators in the INDO-USFWS Wildlife Health Project, and staff members of the Forestry Department of Haryana, India take a blood sample from a tranquilized sambar deer at Hisar Deer Park, Haryana, India. Photo by L. Sileo.

reproduce the center's *Field Guide to Wildlife Diseases, General Field Procedures and Diseases of Migratory Birds* in Chinese. In addition, the center conducted a 6-week intensive training program in diagnostic virology and bacteriology for a veterinarian with the Giza Zoological Garden in Cairo, Egypt. One Australian veterinarian completed 2 years of residency at the center and another received 2 weeks of specialized training in wildlife disease identification and technical assistance.

By means of the Joint U.S.-U.S.S.R. Disease Investigations agreement, two soviet scientists from the D.I. Ivanovsky Institute of Virology visited the National Wildlife Health Research Center to learn more about the center's programs. Two additional scientists from the institute contacted the center to pursue collaborative investigations involving virus diseases of cranes and other wildlife.

The National Ecology Research Center (NERC) and the National Wildlife Health Research Center participated in the Service's 5-year agreement with the Indian government to provide assistance in the development of the Wildlife Institute of India. The health center's part in the project is to develop a strong wildlife health component within the Wildlife Institute's training program and to develop technical capabilities to help combating disease in Indian wildlife. On-site training was provided by health center staff to an Indian veterinarian selected to develop the wildlife health component of their program. Field investigations were begun by chemically immobilizing chital, blackbuck, sambar, and feral cattle to obtain samples for herd health evaluations and wildlife disease investigations. This training program also serves as a vehicle for instruction in chemical immobilization methods and the veterinary care of immobilized animals. On-site in-

volvement by health center staff resulted in the procurement and use of basic equipment needed for field and laboratory support of wildlife disease investigations. Institute personnel were trained in the use and maintenance of this equipment. A 5-year plan was drafted to serve as a guide for future activities involving the wildlife health component of the Wildlife Institute's program. A NERC staff ecologist is overseeing the Wildlife Institute's adoption of geographic information systems (GIS) technology to support research and consulting projects. NERC personnel trained an institute faculty member in GIS planning and operations, and staff exchanges between NERC and the institute will continue until the institute's GIS facility operates independently. GIS projects have started for Kanha National Park, a snow leopard research project in Ladakh, and an economic development study on the Narmada River.

Wildlife Institute of India veterinarian examines an immobilized Chital as part of a herd health monitoring program initiated as an activity of the joint INDO-USFWS Wildlife Health Project.

Photo by J. Dein.



In other research and training activities, NERC biologists

- continued research and training activities in southern Peru, where Peruvian students and professionals were trained in sampling protocols for studies of biological diversity;
- provided technical assistance to counterparts in national universities and museums in Peru and to the Mexican Wildlife agency (SEDUE);
- participated in the Smithsonian Institution's Biological Diversity of the Gulanas program;
- participated in a 1989 joint U.S.-U.S.S.R. Sea Otter Workshop in San Francisco, California;
- prepared a cooperative paper with Soviet scientists on the geographic variations of sea otters;
- assisted international counterparts by providing scientific literature and training to personnel at institutions and agencies in Costa Rica, Ecuador, Fiji, Mexico, Peru, and Samoa;
- served on graduate student committees and advised several students from other countries;

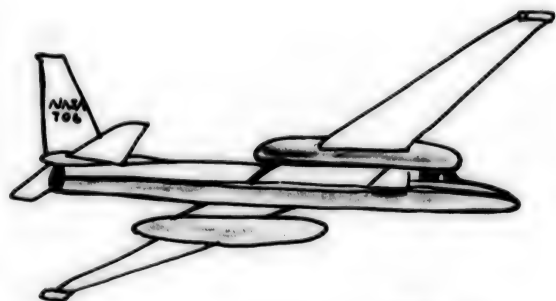
- provided technical assistance to numerous international researchers on specimen identification as well as other requested information; and
- hosted a Korean scientist from the Forestry Research Institute in Seoul, Korea, while he was trained in wildlife management and impact assessment technologies.

National Fisheries Research Center

The National Fisheries Research Center in Seattle, Washington, in cooperation with the Service's Region 1 (California, Hawaii, Idaho, Nevada, Oregon, and Washington), the National Marine Fisheries Service, and the University of Washington is developing a Center of Excellence for International Research in Fish Health and Fish Ecology. This center will include resident quarters for visiting scientists.

In other activities, the University of Zululand and the University of the North, two universities in South Africa, asked a National Fisheries Research Center scientist to give 30 days of technical assistance and training on aquaculture, fish physiology, and fish diseases. In addition, the center had visiting research scientists from four countries: Canada, a 1-year research project; Italy, a 6-week training session on detection and confirmation of infectious hematopoietic necrosis (IHN) virus, the most serious viral disease in salmonid fishes in the United States, at the request of the U.S. State Department; Japan, a 3-month research project; and France, a 1-year research project.

Technological Advances



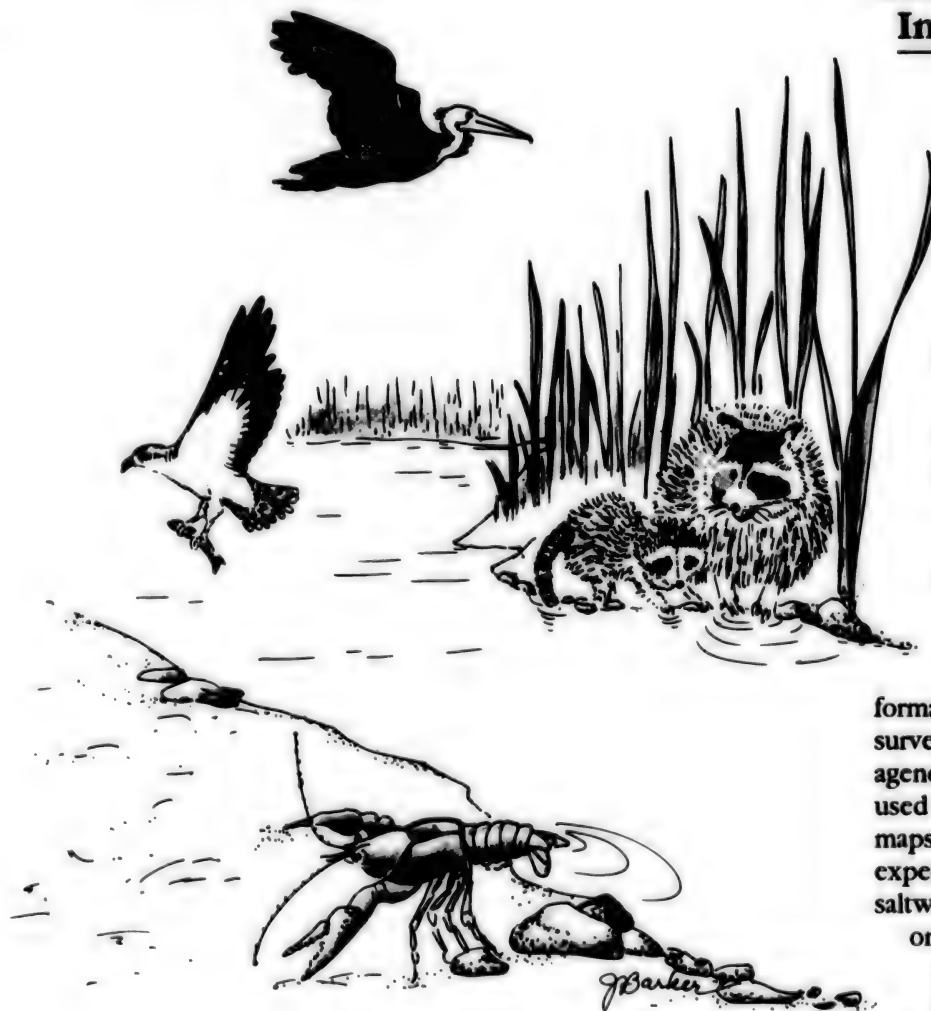
Fish and Wildlife Service researchers are increasingly taking advantage of computerized geographic information systems (GIS's), computer models, video, satellite telemetry, and other established and emerging laboratory and field techniques.

Geographic Information Systems

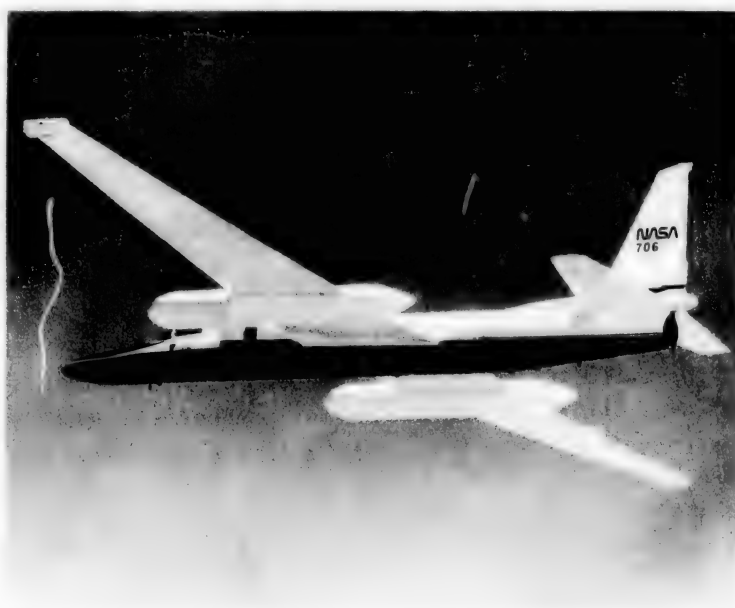
Geographic information systems (computer systems for collecting, managing, and analyzing data) are effective tools for spatial analysis and cartographical display of site-specific geographic data.

Update of Coastal Louisiana Wetlands

The National Wetlands Research Center updated information on Louisiana coastal wetlands with aerial photographs and information from an attendant ground survey by several State and Federal agencies in 1988-89. These data are used to produce digitized habitat maps for a GIS. This information is expected to reveal recent effects of saltwater and freshwater intrusion on the vegetation and water regimes of coastal wetlands, enabling biologists to evaluate effects of environmental changes on fish and wildlife. Previous information about coastal wetlands dates from the mid-1950's and late-1970's,



For 4 weeks in 1988-89 this NASA ER-2 aircraft flew over the Louisiana coastal zone collecting infrared photography and digital imagery for a geographic information system that will help scientists analyze wetland loss.

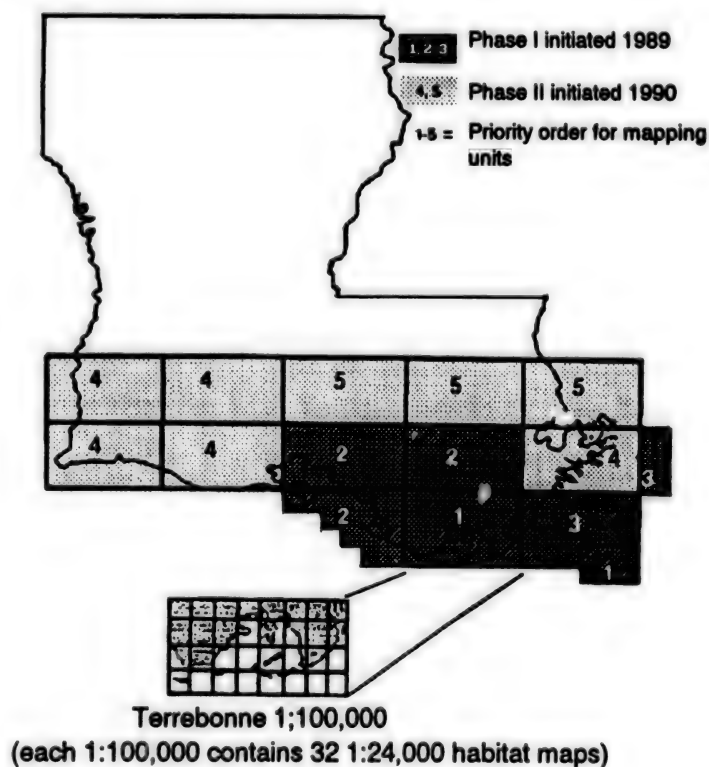


when an estimated 48 square miles of wetlands were lost each year. Surveys of selected areas in the early 1980's had suggested that the rate of

wetland loss was decreasing for parts of the coast but continued to be high in many areas.

Aerial photographs were taken from a National Aeronautics and Space Administration (NASA) ER-2 aircraft, a modern version of the U-2

The Service uses aerial photography to create habitat maps of the Louisiana coastal zone at a scale of 1:24,000, corresponding to U.S. Geological Survey topographic quadrangle maps. This information should reveal recent effects of saltwater and freshwater intrusion on the vegetation and water regimes of coastal wetlands.



reconnaissance plane. For 4 weeks, infrared photography and digital imagery were collected. An altitude of 65,000 feet and speeds of 400 knots allowed the aircraft to cover a large area of the earth's surface in one mission while carrying a heavy load of gear, including a large-format mapping camera and a multispectral digital imaging scanner. Missions covered 21 parallel east-west flightlines over coastal Louisiana.

During the flights, 110 private citizens and representatives from government agencies, universities, private companies, and hunting clubs collected data for the same area on the ground. They recorded data on observation time and location; tidal conditions; water level, clarity, and salinity; water current speed and direction; plant species and condition; percentage of surface covered by plants for selected areas; wind direction and speed; visibility; relative humidity; temperature; and any recent precipitation. The center and the National Wetlands Inventory (NWI) are using this information to verify and interpret the high-altitude photography (at a scale of 1:24,000) in 320 cover maps.

San Francisco Bay Project

The National Wetlands Research Center and the U.S. Environmental Protection Agency (EPA) delineated and analyzed wetland and upland habitats in the San Francisco Bay region (including San Francisco, San Pablo, and Suisun bays) for inclusion in a GIS.

In 1985, 106 quadrangles (U.S. Geological Survey scale 1:24,000) of wetland and upland habitats were mapped by using high-altitude color infrared aerial photography (scale 1:65,000). To develop a trend analysis of wetland change for portions

of the bay area, researchers interpreted a second set of color infrared aerial photography from 1976 (scale 1:130,000) for 44 quads and a third set of black and white aerial photography from 1956 (scale 1:24,000), which was photointerpreted for 20 quads of the lower bay. The center digitized these maps and analyzed them with the Map Overlay and Statistical System (MOSS) software.

The analysis of wetland change focused on the bay margin, designated as the Bay Zone. In the Bay Zone, 220,600 of 688,300 acres are open water, 65,000 are intertidal mud flats, and 35,000 are tidal marsh. Salt and crystallizer ponds (a type of secondary evaporation pond) covered approximately 36,500 acres, mostly in the South Bay, and over 58,000 acres were diked marshes. Estimates were calculated for wetland change in the South Bay by using the 1956 and 1985 wetland maps and data. An overall 6% decline of wetlands was noted over the 30-year period; however, about 57% of the estuarine intertidal emergent vegetation was lost. Urban areas increased by 56%.

Numerous agencies that regulate and manage the wetlands of the San Francisco Bay area have used these data: EPA and the Fish and Wildlife Service for site-specific jurisdictional determinations; the San Francisco Bay National Estuarine Program for background and as baseline data for continuing research and reports; and the State of California and conservation and environmental groups for promoting, protecting, mitigating, and restoring the bay's wetlands.

Contaminants in Mobile Bay Estuary

The National Wetlands Research Center used a GIS and cartographic modeling techniques to predict potential impacts of contaminated sediments on selected

natural resources in Mobile Bay, a large, productive estuary on the central Gulf of Mexico. The bay and its natural resources provide a large proportion of the economic base of the surrounding counties. As such, Mobile Bay is the site of many competing demands including shipping and commerce, tourism and recreation, fishing and shellfishing, oil and gas development, and national defense. Resource managers must balance these conflicting demands and plan and implement policies and programs to preserve the natural resources of the bay without compromising the economic well-being of the surrounding communities. Consequently, resource managers must know not only if resources are at risk, but also exactly where the risks are greatest. Researchers used a GIS to identify locations of present resources and contaminants.

Researchers assembled and entered into the system locations of estuarine parameters, contaminant loads, habitats, fish and wildlife distributions, and other features. A data base on the toxicity of chemicals that enter the bay was also compiled. Both the simple overlay and the cartographic modeling capabilities of the GIS are now being used to highlight areas at low, medium, and high risk of contamination of specific resources by specific contaminants.

For example, a localized zone of zinc concentration near the mouth of Mobile Bay was discovered from superimposing zinc concentrations in the sediments, sediment grain size distribution, oyster reef distribution, and water salinities. The accumulation is in a zone of clay sediments with a high cation exchange capacity and higher salinity. The result is zinc that is more mobile and available to the organisms in this location.



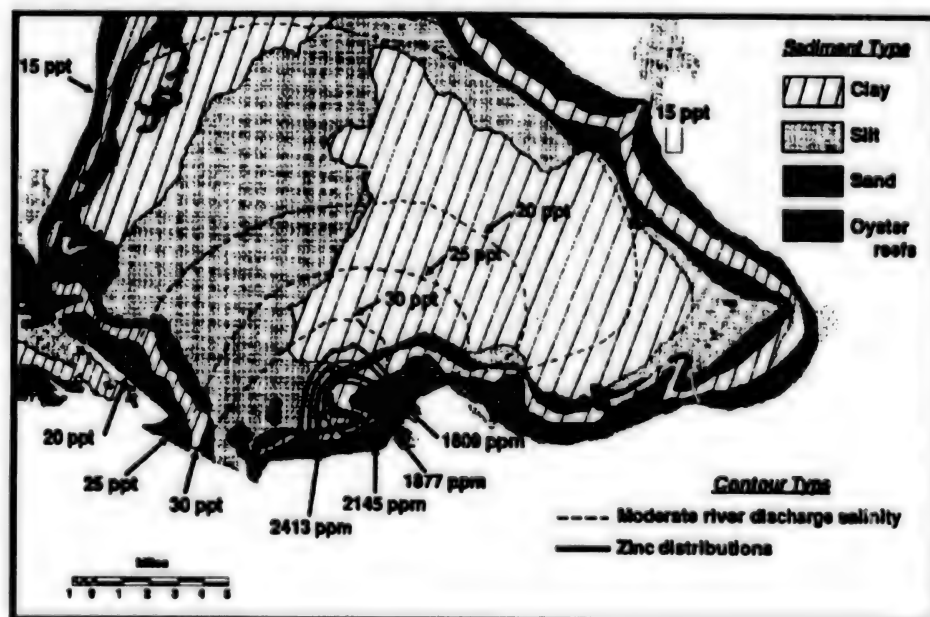
This geographic information system integrates map data, airborne video, and waterfowl counts to produce estimates of habitat conditions and duck production. The system is being used in Regions 3 and 6.

Spatial analyses, as demonstrated by this example, provide a rational basis for management decisions. The assessments can be used to justify expensive chemical-testing programs, pinpoint sample

sites, identify resources that are at greatest risk, locate the origin of the risk, eliminate risks, and restore resources.

A multivariate data base enables researchers to construct a large number of models to examine various hazards to the ecosystem.

Using a computerized geographic information system, researchers discovered a localized zone of zinc concentration with a high cation exchange capacity and a high salinity zone that make the zinc more mobile and available to organisms.



GIS in Duck Studies

In 1986, the Northern Prairie Wildlife Research Center began developing a system for estimating habitat conditions, size of duck populations, and duck production in the Prairie Pothole Region. The system was designed to furnish estimates by Wetland Management District and land ownership class. The system's goals are consistency of estimates among areas and years, maximum use of existing data, rapid execution of complex procedures with microcomputers, and documentation of changes in the parameters. Fish and Wildlife Service Regions 3 and 6 adopted the system in 1989 and established field offices at Fergus Falls, Minnesota, and at Bismarck, North Dakota.

Direct measurement of breeding populations and production in ducks is difficult and expensive. Measurement of habitat by abundance and type, however, is relatively simple and inexpensive with remote-sensing technology. Because of the relationships between abundance of wetland and size of breeding populations in an area, and between abundance and type of nesting habitat and duck recruitment rates, models can be used in place of direct measurements and even can improve the precision of surveys without greatly increasing cost.

Researchers obtain baseline habitat conditions from habitat maps digitized by the National Wetlands Inventory and assess annual changes in habitat with video. Both sets of images are processed by microcomputer with a GIS, the Map and Image Processing System. The models were developed with data from long-term studies by the center and are calibrated annually with data on duck density from two annual ground surveys in sample wetlands from each Wetland Management District.

Data from past years demonstrate the effect of drought in the Prairie Pothole Region. Although the number of ducks and ponds plummeted in 1987-88, duck density per pond increased in the remaining ponds. Some recovery occurred in most of the region in 1989, but drought persisted and intensified in central North Dakota. Breeding populations and production of recruits followed changes in water conditions.

Duck production by land ownership class was also studied. Although land owned in fee-title by the Service represents a small percentage of the total land surface, it produces a disproportionately high percentage of the ducks, especially in Minnesota. Most ducks are produced on private land. But, Minnesota wetlands in the Prairie Pothole Region are less abundant on private land than on land owned by the Service or lands with an easement retained by the Service. Pairs attracted to wetlands on these tracts make an important contribution to production. To meet production goals that the North American Waterfowl Management Plan and Prairie Pothole Joint Venture stipulated, habitat on these lands must be preserved and enhanced.

Great Lakes Maps

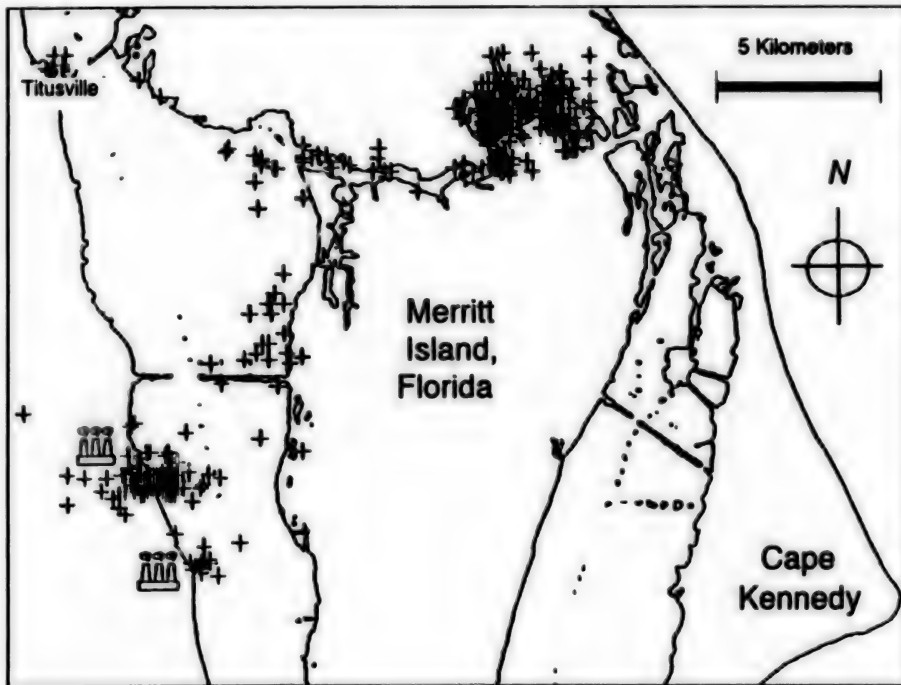
The National Fisheries Research Center—Great Lakes used side-scan sonar, a remotely operated underwater vehicle, a four-person mini-submarine, and a computer-linked GIS to map substrate and bathymetry of historical spawning grounds of lake trout in the Great Lakes. Researchers use these maps to guide lake trout stocking and to accelerate reestablishment of self-sustaining lake trout stocks.

The center mapped one to four spawning grounds in each of the five Great Lakes and evaluated each

spawning ground for its potential to support spawning and production of viable fry by the contemporary shallow water strains of lake trout now being stocked in those waters. At several of the more degraded locations, researchers are conducting comprehensive field bioassays to determine causes of limited fry production. At sites of high environmental quality, fishery managers are using the maps to pinpoint locations where lake trout can be stocked with the assurance that returning adult fish encounter suitable habitat for spawning and fry production.

Manatee Research and Management

The National Ecology Research Center completed a decision-support system called QuickMAP to assist in expedient transfer and use of vital geographic information for conservation of manatees—an endangered species. Investigators used satellite and conventional radio telemetry to record manatee movement patterns. They estimated mortality by salvaged carcasses that were reported via a telephone hotline. The Florida Manatee Recovery Plan is a joint enterprise by 13 Federal and State agencies, private industry, and public interest groups. The QuickMAP system consists of microcomputer software that translates information among the various formats used by these agencies. The software provides entry of supplemental geographic information such as locations of freshwater springs and power plant effluents that manatees use as refuges during cold weather. Scientists can quickly generate special maps to illustrate problems and inform developers about threats to the survival of manatees from proposed development.



The figure shows the locations of an adult female manatee monitored by satellite through Service ARGOS from December 1986 to June 1987. The National Oceanic and Atmospheric Administration's shoreline data span six U.S. Geological Survey quadrangles. The densest clusters of use are in protected Florida waters of Banana Creek on the Merritt Island National Wildlife Refuge and near the warm-water effluent from power plants in the lower left of the photo.

In Florida, four Fish and Wildlife Service offices use the prototype system. As part of this project, shoreline information from the National Ocean Survey's digital data base is being converted for use with manatee in-

formation at a level of detail comparable with U.S. Geological Survey 7.5-minute quadrangle maps. The center uses the ARC/INFO Geographic Information System to do the conversion, and it disseminates shoreline

data bases to the Florida Department of Natural Resources and to Service field offices for the QuickMAP system. More than 200 quadrangle maps for nearly the entire coast of Florida are now in use.

West Indian manatee outfitted with a floating antenna and radio transmitter for telemetry study.



Models

Models are computer programs that simulate and predict real-world conditions.

Forest Succession Model

The National Wetlands Research Center has developed a computer succession model called Forflo that predicts changes in the composition of canopy trees in bottomland hardwood forests. In 1989, the center used Forflo to predict the impacts of a proposed flood control project in the Passaic River basin of northern New Jersey. Scientists continue to test and improve the model and have increased the number of potential users by producing a microcomputer version.

Coastal Ecosystem Landscape Spatial Simulation Model

The National Wetlands Research Center and Louisiana State University developed a Coastal Ecosystem Landscape Spatial Simulation model that predicts habitat succession and changes in wetland landscapes of coastal Louisiana. Scientists used the model to estimate the effects of proposed levee extension projects in western Terrebonne Parish and are now modifying the model to evaluate freshwater diversion plans for rejuvenating eroding marsh habitat in the Barataria Basin. This newest version runs on a Macintosh microcomputer and incorporates an innovative design of parallel processing to enhance computational speed and portability. The model is used to examine natural processes of wetland loss including subsidence, salinity intrusion, and high-impact storm events, as well as human activities.

Habitat Management Evaluation Method

The National Ecology Research Center developed and applied a microcomputer program, the Habitat Management Evaluation Method (HMEM), to help wildlife managers design cost-effective habitat management plans. The HMEM links information on the responses of different species to habitat, changes in habitat due to management, and costs of managing habitat. The premise of HMEM is that the best plan among all alternatives effective for achieving specified management goals is the one with the smallest dollar cost. This method measures the dollar cost, discounted and amortized over time, required to achieve a specified management goal; the goal is described in Habitat Units (Habitat Suitability Index multiplied by area). The HMEM helps determine which habitat improvement activities are most cost-effective for a species and how much of a management activity can be applied and still remain cost-effective.

The center used HMEM to develop plans for intensive management of a 700-acre wildlife area and for an extensive low-cost per acre management of a 17,000-acre forest. The cost-effectiveness concept is appropriate for many land management problems, including State and Federal refuge management, mitigating habitat losses due to construction projects, and forest management planning.

The present version of HMEM has limited ability to model spatial constraints on habitat management. The center plans to link the cost-effective modeling of HMEM with the spatial modeling capabilities of microcomputer-based GIS. When this linkage is completed, a user will have greater ability to determine where habitat management is most cost-effective.

Negotiations Model

The National Ecology Research Center developed a model to aid biologists in planning and conducting negotiations involving Federal permits and licenses. Such negotiations include working with developers on Federal Energy Regulatory Commission licenses and with the Army Corps of Engineers on Section 404 and Section 10 permits.

The Legal Institutional Analysis Model (LIAM), a software package with various information from the social sciences, assesses alternative approaches to resolve disputes. Analysis with LIAM results in recommendations for negotiation style and strategy.

In workshops for Service personnel, State agencies, and hydropower developers, the model was useful in successful resolution of conflicts. Use of the model is taught in formal training sessions, and the software is available for distribution. Users report that the model has improved decision making and reduced conflict over Federal permits and licenses.

Instream Flow Incremental Methodology

The California Cooperative Fishery Research Unit tested several optional techniques of the Instream Flow Group #4 hydraulic simulation model that compare predicted stream velocities and weighted usable area (WUA) values with measured stream velocities and benchmark WUA values at different levels of flow. Actual velocity and WUA values were most accurately simulated by using a combination of results from the three one-flow techniques. The two no-velocity flow techniques simulated stream velocities poorly, but general trends in predicted WUA values were quite similar to benchmark values.

The same unit also developed habitat utilization curves for fry and juvenile steelhead in a small moderate-to-high gradient stream and compared them with three standard habitat utilization curves. Comparisons were made of the amount of WUA generated by the curves from the instream flow incremental methodology computer program. Site-specific curves had narrower ranges than standard curves and generated much less WUA for fry and juvenile steelhead at all flows above 3 cubic feet per second. Comparisons revealed that stream size, gradient, and other habitat characteristics must be compared before habitat utilization curves from one stream are applied to another.

Interactive Instruction for Model

The National Ecology Research Center uses interactive instructional exercises for transferring computer-based technology in its Physical Habitat Simulation Model (PHABSIM) training courses. The exercises include restructured lab materials designed for in-class and out-of-class self-paced computer

tutorials. Ten lab exercises demonstrate the capabilities and limitations of PHABSIM and complement the software documentation. The tutorials are set up in a lesson-by-lesson format. The lessons explain how to run the programs, understand the results, and interpret the reliability of results.

The center also developed a new user-friendly front end for PHABSIM. This new software separates the PHABSIM user from the microcomputer's operating system. The center is testing a set of instructional material in a classroom setting.

Video

The Fish and Wildlife Service is increasing its use of video technology in various settings.

Great Lakes Artificial Reefs

The National Fisheries Research Center—Great Lakes is using side-scan sonar and a remotely operated vehicle to assess five artificial reefs in Lakes Erie and Huron. Creation of artificial reefs for improving sport fisheries is a relatively new technique. Researchers used the side-

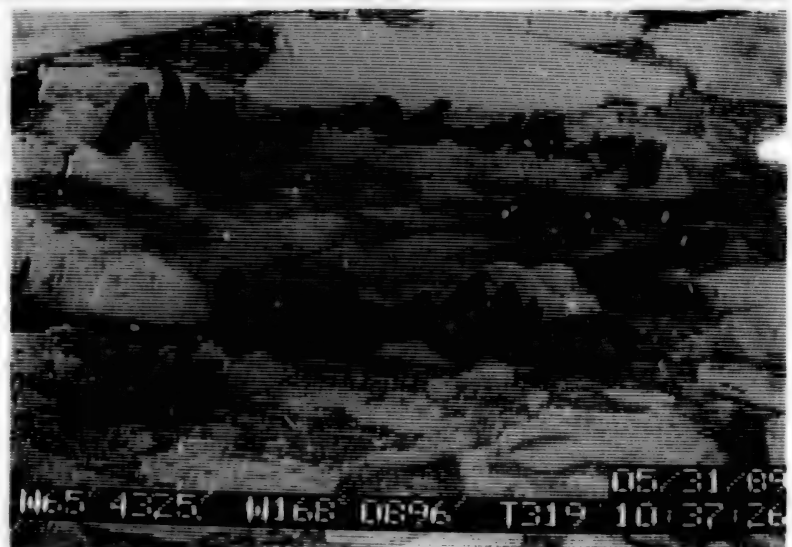
scan sonar records to evaluate the overall boundary and continuity of each reef. Data from ROV video were useful in assessing the physical condition of the reef, including the average height above the surrounding base, average size and type of material used, type of base supporting the reef, amount of sedimentation, and relative visibility around the reef. With the remotely operated vehicle, investigators also obtained initial biological data, such as periphyton and macrophyte growth on and around the reef, invertebrate colonization, and presence or absence of fish.

With the side-scan sonar and the remotely operated vehicle, scientists identified several differences in the physical makeup of these artificial reefs. Most differences were due to construction methods and materials. Whether or not these differences actually affect the reef's ability to support the fishery for which it was intended is currently being determined by further biological assessment.

Videography in Alaska

The Alaska Fish and Wildlife Research Center found that high-resolution, true color, Super-VHS airborne video imagery of tundra habitats con-

Color, Super-VHS imagery of walrus hauls out on pack ice had insufficient resolution for a reliable count of individual animals when the image strip-width was greater than 137 yards; however, oblique hand-held video imagery of walrus renders useful documentation of aggregation patterns of walrus. *Photo by D. Douglas, 1990.*



tains about the same information as 1:6,000-scale, 9 inch $\times$ 9 inch aerial photography when the video camera covers a ground strip-width of 109 yards. Because such a narrow area of coverage per transect is required for resolution that is equivalent to photographic techniques, airborne video is not an economical method for mapping large contiguous areas. However, for documenting small or linear features, or for sampling designs with strip or transect methodologies, airborne video has cost-effective potential.

True color, Super-VHS imagery of Pacific walrus hauled out on pack ice had insufficient resolution to reliably count individual animals when the strip-width was 137 yards.

The vertical camera angle combined with a high-contrast environment tends to blend walrus with the dirty ice substrate often associated with haul-out areas. Oblique handheld video imagery of walrus provides useful documentation of aggregation patterns and numbers of individuals. Freeze-frame video playback allows review and recount of walrus groups and comparisons to estimate visual counts. Walrus up to 6/10ths of a mile away can be recorded with a 12-power zoom lens and subsequently counted with video playback. Videography has demonstrated potential for enhancing walrus surveys.

Assessing Riparian Plant Communities

The National Ecology Research Center used airborne videography to assess historical changes in riparian vegetation and geomorphic features along a 10-mile reach of the Cache La Poudre River, Colorado. Researchers used the Map and Image Processing System software to convert information from historical topographic maps and conventional photos to data sets that are compatible with a GIS known as GRASS. They used GRASS to evaluate and quantify spatial and temporal changes in geomorphic features and associated riparian vegetation. Preliminary data analysis indicates that formerly agricultural land

View south along the Cache La Poudre River near Fort Collins, Colorado, in 1954 before (*above*) and after (*below*) clearing of riparian vegetation.



turned into forested alluvial benches, largely because of flood-plain areas being converted to residential parks.

Airborne videography may provide quick and economical assessment of the status of riparian resources along selected river corridors. Linking such information with hydrologic simulation and vegetation-response models might improve predictions of broad-scale response by riparian plant communities to changes in stream hydrology.

Identifying Manatees

Almost all Florida manatees have body scars from injuries by boats. Researchers use these scar patterns to distinguish animals from one another. Thus, each manatee's scar pattern is photographed and filed. Over the years, scientists at the National Ecology Research Center's Gainesville Research Station have collected and cataloged thousands of photographs for hundreds of manatees. The time needed to determine whether sightings were of new or already-cataloged animals increased with size of the collection.

The center used videodisc technology to expedite identification of individual Florida manatees. More than 1,300 scar slides representing 729 manatees were laser-imprinted onto a videodisc (one videodisc holds more than 100,000 slides) and integrated with a data base of scar codes (descriptions of the scar patterns) for each animal. Now researchers can key the scar patterns of a newly sighted animal into the system, and in seconds the system displays potential matches on a television screen. Alternatively, a particular animal may be displayed by keying in its specific scar pattern or common name. This technology saves hundreds of hours of examining slides.

Videodisc Training

Training employees in new technologies can be expensive, inconvenient, or unavailable. Consequently, the National Ecology Research Center examined the applicability, efficiency, and cost-effectiveness of training by videodiscs.

The center converted a traditional software course to videodisc format. A design team modified existing course materials and developed new materials for an interactive format. Researchers developed software for videodisc and prepared instructional graphics. Later, they combined the linear video, graphics, and text on a 1-inch tape, and a disc-mastering facility prepared a videodisc.

The center is now sending videodiscs and equipment to several field offices to compare the effectiveness of the videodisc course against the traditional course. Each participant completes pre- and post-tests and a questionnaire. Investigators compare test results between the two groups of participants to determine the effectiveness and cost of the videodisc as a training medium.

Satellite Telemetry

The Alaska Fish and Wildlife Research Center is using daily satellite images of Alaska, western Canada, and eastern Russia for planning survey missions and for selecting scenes for archival and digital analyses. The satellite imagery is Advanced Very High Resolution Radiometer FAX renditions.

In 1989, the center received satellite telemetry data for about 40 polar bears, 30 caribou, 6 Pacific walrus, 6 brown bears, 6 muskoxen, and 2 moose. Muskoxen and moose are studied jointly with the Arctic National Wildlife Refuge;

polar bears and walrus are studied jointly with the Soviet Union.

Over 70 megabytes of satellite tracking data were received via the Service's ARGOS, a joint project by the Centre National d'Études Spatiales of France, the National Oceanic and Atmospheric Administration, and NASA. Only a small fraction (1-3%) of the data had format inconsistencies or missing information. The data-processing structure of ARGOS is being modified and the Local User Terminal at the Fairbanks Field Station is being upgraded with a D-band satellite tracking dish, improving real-time satellite data acquisition, and locational derivation over the same system with a very high frequency (VHF) antenna.

Special Problems

Occasionally, special problems arise in the laboratory or field that require researchers to develop or apply new technologies and techniques.

Carbon Filter System Removes Malachite Green

For more than 40 years, fish culturists at Federal, State, and private hatcheries have used malachite green, an effective fungicide for the treatment of fish and fish eggs. When this compound was identified as a potential teratogen, the Service restricted its use in national fish hatcheries. Because an effective fungicide to replace malachite green is not available, the U.S. Food and Drug Administration granted the Service a permit to use malachite green at specified fish hatcheries that produce fish for the restoration of depleted stocks of Atlantic salmon, Pacific salmon, striped bass, Atlantic sturgeon, and shortnose sturgeon. State hatcheries in Idaho, Oregon,

and Washington also used malachite green under the Service's permit, which required that the fungicide be removed from all treated water after March 1989.

The National Fisheries Research Center in La Crosse, Wisconsin, designed a study to (1) determine the type of filter and kind of carbon that were most efficient at removing malachite green from water and (2) demonstrate that carbon filters can be used to remove malachite green from water used for egg incubation or to hold adult salmon before spawning. Minicolumn simulation studies showed that 8×30 mesh-size granular carbon was effective for continuously removing malachite green from water for 230 days at a flow rate of 500 gallons per minute and for only 62 days at a flow rate of 1,000 gallons per minute. The removal capacity at the slower flow rate was 69 mg of malachite green per gram of carbon.

A filter system with 2,000 pounds of activated carbon in each of two chambers was effective for removal of malachite green from treated water in salmon egg incubation units at the designated flow rate of 50 gallons per minutes (4 gallons per minute per square foot) and also at faster rates.

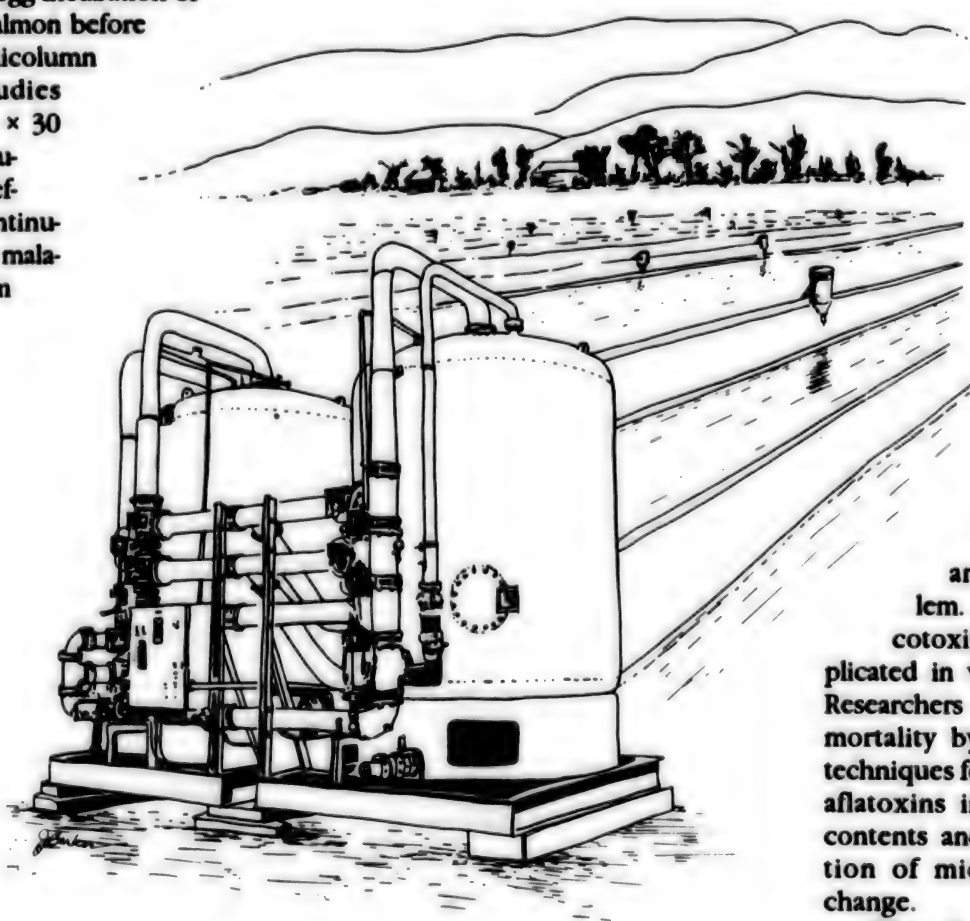
A filter system with 20,000 pounds of activated carbon in each of two chambers was effective for removal of malachite green from treated water in adult salmon holding ponds at flows of 500 gallons per minute (6.4 gallons per minute per square foot) and greater. The removal efficiency was 99.8% after 105 hours of operation, and the adsorption capacity of the system was projected to be 20 or

lons per minute and the unit on the egg incubation effluent could accommodate flows up to 100 gallons per minute. If greater flows are necessary, multiples of these units or other sized units could be installed. The carbon filtration systems are readily available from commercial sources.

Mycotoxin Screening

Mycotoxins are highly toxic compounds produced by some fungi under appropriate temperature and moisture conditions. Waterfowl deaths caused by mycotoxins in food material, particularly in waste grain, are an emerging problem. Aflatoxins are mycotoxins commonly implicated in waterfowl die-offs. Researchers diagnose aflatoxin mortality by using analytical techniques for the detection of aflatoxins in gastrointestinal contents and by the observation of microscopic tissue change.

The National Wildlife Health Research Center developed the capability to test for four different aflatoxins. The procedure requires initial screening of a sample with a competitive enzyme immunoassay test. If the result is positive, the sample extract is further purified and applied to thin layer chromatography for identification and quantification. The center is also developing a screening method



more years of routine hatchery operation.

The filter units were also effective for flow rates up to three times greater, and efficiency improved when treated water was passed through two chambers in series rather than through a single chamber. In series, the unit on the adult salmon holding pond effluent could accommodate flows up to 1,000 gal-

for several other mycotoxins, including ochratoxin A and T-2 toxin.

Mobile Popnet

Because of the difficulty of obtaining good fish population estimates in lakes, the Colorado Cooperative Fish and Wildlife Research Unit developed a mobile popnet (i.e., an inflatable lift net) to quantitatively sample fish in a known volume of water. This "bottom-up" sampling device is effective in estimating fish populations of known size and requires little more effort to employ than conventional fish-capturing techniques. Fish captured

with popnets are unharmed, eliminating questions about survival often associated with other fish-sampling gears traditionally used for estimating fish population sizes in lakes.

Determining Body Fat Without Sacrificing

Wildlife scientists have long been interested in the physiological condition of populations and individuals. Traditionally, however, they have had to sacrifice animals to analyze body tissues for lipid levels to determine their condition. A new technology using total body electrical conductivity now accurately de-

termines body fat levels in live animals in only 30 seconds. National Ecology Research Center biologists use this technology to evaluate lipid dynamics of migrating shorebirds on the Great Plains.

The new technology is a major breakthrough in field physiology studies because lipid dynamics of individual animals can be evaluated relative to experimental treatments and natural processes. The technology also has great implications for conservation studies of endangered species or populations of only a few individuals in which sacrificing a single animal represents a major loss to the genetic diversity of the population or species.

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**UNITED STATES DEPARTMENT OF
THE INTERIOR**

Manuel Lujan, Jr., Secretary

**Fish and Wildlife Service
Region 8—Research and Development**

As the Nation's principal conservation Agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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